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ORGANIC MERCURY FUNGICIDES AND DISEASE RESISTANCE IN THE CONTROL OF SLENDER WHEAT GRASS SMUT[1]

By A. W. Henry[2], S. B. Clay[3], and J. R. Fryer[4]

Abstract

The common smut disease of slender wheat grass, *Agropyron pauciflorum*, was completely controlled by treatment of naturally or artificially smutted seed with three organic mercury dust fungicides containing as active ingredients ethyl mercury phosphate, methyl mercury nitrate and methyl mercury phosphate, respectively. Applications of one-half ounce per bushel gave as satisfactory control as higher rates and caused no appreciable seed injury after storage of the treated seed for one year.

Several Alberta collections of wild plants of *Agropyron pauciflorum* and of intermediates between *Agropyron pauciflorum* and *Agropyron subsecundum* proved highly resistant or immune from smut when artificially inoculated at Edmonton, while other collections proved moderately or highly susceptible.

Fyra, a superior variety of slender wheat grass which has been distributed for several years by the University of Alberta, has been shown to be highly smut resistant but not immune.

As long as smut-susceptible strains of slender wheat grass are grown, and until immune varieties are developed and generally distributed, continuance of seed treatment is advised.

Introduction

The common smut of slender wheat grass, *Agropyron pauciflorum* (Schwein.) Hitchc., is the chief smut disease affecting a cultivated forage grass in western Canada. This disease was first reported from Saskatchewan, and the causal fungus was identified as *Ustilago bromivora* (Tul.) Fisch. v. Waldh (4). More recently Fischer has proposed that this smut fungus be included in the composite species *Ustilago bullata* Berkeley (1). Owing largely to the fact that it is seed borne, this smut has become widely distributed in the central part of the North American continent, and has assumed considerable economic importance especially in crops intended for seed purposes. Anyone who contemplates growing slender wheat grass is consequently well advised to take precautions against the disease.

Up to the present time the principal control measure suggested has been seed treatment with formaldehyde. This method was first found effective in the prevention of this smut by Fraser and co-workers (2, 3, 4). Their treatment consisted in soaking the seed for five minutes in a 1–320 (one part commercial formaldehyde to 320 parts of water) solution, covering for two hours

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Contribution from the Department of Field Crops, University of Alberta, Edmonton, Alberta, with financial assistance from the National Research Council of Canada.
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and then spreading out to dry. Tests made over a period of several years from 1918 to 1926 not only gave excellent control of the smut, but also showed no evidence of seed injury.

Fraser and Scott (4) also experimented with a dry fungicide, namely, copper carbonate dust, but failed to control the smut satisfactorily.

The possibility of preventing this smut by regulation of the time of seeding was investigated by Padwick and Henry (6), but it was concluded by them that this method held little promise of success.

The use of smut-resistant or immune varieties or strains of slender wheat grass would obviously be a desirable preventive measure, as it has proved to be in various other crops. As far as we are aware, however, the possibility of control by this method has not been previously explored and no reports of smut resistance in this grass have come to our attention.

Objects of Present Investigations

The studies reported here were undertaken with two objectives in view, namely, finding (i) a fungicide which would successfully control this smut disease when used for seed treatment in a dry or dust form, and (ii) resistant or immune strains of the grass host which might be used to replace susceptible varieties or strains, or to serve as parent material for breeding work.

Seed Treatment Studies

Although, as has been pointed out, Fraser and Scott (4) have obtained excellent control of slender wheat grass smut by treating infested seed with a 1–320 formaldehyde solution, this treatment has several obvious disadvantages. Compared with a dry treatment it is less convenient, more time consuming and less suitable for use in advance of seeding time. Moreover, there is danger of seed injury, especially in the hands of careless users who may apply overdoses. While Fraser and Scott (4) report no evidence of seed injury, and we have had relatively little, Morwood (5) found that formalin adversely affected germination when applied to the seed of *Bromus unioloides*.

The only dry treatment heretofore reported to our knowledge for the control of slender wheat grass smut is the copper carbonate dust treatment. Fraser and Scott (4) used copper carbonate, but failed to obtain satisfactory smut control with it. Other dusts, however, have been used for the treatment of grass seed. The work of Morwood (5) on *Bromus unioloides* should again be noted in this connection, since he used two organic mercury dusts, Abavit B and Ceresan, for the control of a smut disease similar to that affecting slender wheat grass. The applications which he used were heavy, namely, three ounces per 20 pounds of seed. These reduced infection from 83.5% in the controls to 0.1%.

Experimental Methods

Investigations on the control of slender wheat grass smut by seed treatment with fungicidal dusts were begun at the University of Alberta in 1931, but no conclusive data were obtained until 1936. In the early experiments* little

* *The assistance of Messrs. G. W. Padwick and J. B. Skaptason in connection with these experiments is gratefully acknowledged.*

or no smut developed in the untreated checks, so no conclusions could be drawn from them. These failures were at first attributed to unfavorable soil conditions, but in the light of the studies of Padwick and Henry (6) and of those reported in the latter part of this paper, they now appear to be due to the use of a smut-resistant variety of slender wheat grass.

In 1936 extra precautions were taken to insure smut infection in the checks. To this end a composite sample of seed was used for the main experiment. This consisted of three commercial lots each obtained from a different local seed store. This seed mixture was then dusted with a composite collection of smut spores obtained from five separate Alberta sources. Three were obtained from smutty stands of slender wheat grass growing in the vicinity of Edmonton, one from Strathmore in southern Alberta, and one from Vermilion in the east central part of the province. In another experiment naturally smutted seed was used, as it was thought possible that it might respond differently to seed treatment than would artificially smutted seed. The naturally smutted seed was obtained in 1936 from plots at the University that contained a considerable proportion of smutted plants.

The fungicidal values of five chemicals, namely, formaldehyde, copper carbonate, ethyl mercury phosphate, methyl mercury nitrate and methyl mercury phosphate were tested on the artificially smutted seed, but only the last three were tried on the naturally smutted seed.

The formaldehyde treatment, the only wet treatment tested, consisted in these experiments of a two-minute soak in a solution containing one part of commercial formaldehyde and 320 parts of water. The treated seed was then covered with sacks for four hours and finally air-dried before seeding.

The dry chemicals or dusts were applied simply by shaking a weighed amount of each in a flask with 25 grams of seed. A copper carbonate dust containing 50% copper carbonate was applied at the rate of two ounces per bushel of seed and three organic mercury dusts, namely, ethyl mercury phosphate*, methyl mercury nitrate**, and methyl mercury phosphate†, with mercury equivalents of 3.8, 1.5 and 3% respectively, were each applied at three different rates, namely, one-half, one and two ounces per bushel of seed.

After treatment the seeds were counted and later sown in the field at the rate of 200 seeds per rod row. Four replications of each treatment were sown. In spite of being sown late in the summer, namely, on August 3, 1936, the stands survived the winter well and headed normally the following summer.

The smut data were taken by counting the number of heads per row and recording the smutted heads as a percentage of the total number.

Smut Control in Field Experiments

The field results from the seed treatment experiments are given in Tables I and II. The smut data are averages of four replications in each case. It will be noted that two counts are given for each treatment. These represent

* *Sold under the trade name of New Improved Ceresan.*
** *Sold under the trade name of Leytosan.*
† *Sold under the trade name of Leytosan P.*

results from two crops in 1937. After the first one had headed and was counted, a second one was allowed to head and a separate count was made on it. Table I gives the results obtained for plants from seed which was both naturally and artificially smutted.

TABLE I

RELATIVE EFFECTIVENESS IN SMUT PREVENTION OF DIFFERENT FUNGICIDES USED FOR SEED TREATMENT OF BOTH NATURALLY AND ARTIFICIALLY SMUTTED SEED OF SLENDER WHEAT GRASS

Treatment	Amount of fungicide per bushel, oz.	Percentage of heads smutted		
		First crop	Second crop	Average
None—check (naturally smutted)	0	5.5	7.8	6.6
None—check (naturally and artificially smutted)	0	14.4	16.8	15.6
Formaldehyde 1–320	–	0.0	0.0	0.0
Copper carbonate	2	5.4	4.2	4.8
Ethyl mercury phosphate	½	0.0	0.0	0.0
Ethyl mercury phosphate	1	0.0	0.0	0.0
Ethyl mercury phosphate	2	0.0	0.0	0.0
Methyl mercury nitrate	½	0.0	0.0	0.0
Methyl mercury nitrate	1	0.0	0.0	0.0
Methyl mercury nitrate	2	0.0	0.0	0.0
Methyl mercury phosphate	½	0.0	0.0	0.0
Methyl mercury phosphate	1	0.0	0.0	0.0
Methyl mercury phosphate	2	0.0	0.0	0.0

It will be seen from the data in Table I that the formaldehyde treatment and all the mercury dust treatments completely controlled the smut, whereas copper carbonate dust treatment did not. In the case of the mercury dusts it is noteworthy that the one-half ounce rate in each case was as effective as heavier applications.

The mercury dusts were tested further on another sample of seed which was naturally smutted only. In this case only one rate of application, namely one ounce per bushel, was used. The results are given in Table II.

The effectiveness of the mercury dusts in controlling this smut is again shown in Table II. When used at the rate of one ounce per bushel all three dusts tested gave perfect control. While they have given no better control

TABLE II

RELATIVE EFFECTIVENESS IN SMUT PREVENTION OF DIFFERENT ORGANIC MERCURY DUSTS USED FOR SEED TREATMENT OF NATURALLY SMUTTED SEED OF SLENDER WHEAT GRASS

Treatment	Amount of fungicide per bushel, oz.	Percentage of heads smutted		
		First crop	Second crop	Average
None—naturally smutted	–	9.4	10.0	9.7
Ethyl mercury phospate	1	0.0	0.0	0.0
Methyl mercury nitrate	1	0.0	0.0	0.0
Methyl mercury phosphate	1	0.0	0.0	0.0

than formaldehyde, they have some decided advantages over this treatment, as has already been indicated, and over copper carbonate because of its failure to give complete control. It is true that the percentage infection in the checks in the above experiments is not especially high, but the control is consistent in all tests and would seem adequate for practical purposes.

Effect of Treatments on Seed Viability

The field plots were not sown in such a way as to make possible an accurate estimation of the effects of the treatments on the germinability of the seed, but an examination of the stands in the seedling stage revealed no obvious differences between the treatments or between the checks and the treatments.

Samples of the treated and untreated seed used in the field experiments were, however, saved. These were stored for a year in the laboratory at room temperatures in small stoppered 200 cc. Erlenmeyer glass flasks. Representative samples of this stored seed were then tested for viability in flats of soil in the greenhouse. The results of these tests are given in Table III.

TABLE III

VIABILITY OF TREATED AND UNTREATED SEED OF SLENDER WHEAT GRASS AFTER STORAGE FOR ONE YEAR IN STOPPERED FLASKS

Treatment	Amount of fungicide per bushel, oz.	Per cent emergence				
		A*	B	C	D	Average
None—check	–	92	96	80	98	92
Formaldehyde 1–320†	–	100	76	88	92	89
Copper carbonate	2	92	80	96	100	92
Ethyl mercury phosphate	½	88	92	88	92	90
Methyl mercury nitrate	½	96	90	88	88	90
Methyl mercury phosphate	½	90	88	92	94	91
Methyl mercury phosphate	2	62	64	64	64	64

* *A, B, C and D represent four replicates. The value for each replicate is based on 50 seeds tested, except in the cases of formaldehyde and copper carbonate tests where it is based on 25 seeds per replicate.*

† *The formaldehyde treated seed was not stored. The treatment was applied in this case just previous to seeding time.*

It is evident from Table III that none of the treatments covered in the seed viability tests caused appreciable decreases in emergence except methyl mercury phosphate at the rate of two ounces per bushel. Since the tests were made on seed which had been stored for a year they would seem more likely to disclose any evidences of seed injury than tests made immediately or shortly after treatment. It should be noted especially that the mercury dusts at one-half ounce per bushel caused no significant reduction in emergence nor did formaldehyde applied immediately before seeding and, as will be remembered, all these treatments controlled the smut disease completely. Copper carbonate caused no seed injury, but, as has been noted, it failed to control the smut satisfactorily. While the two-ounce rate of mercury phosphate

caused serious injury, it is unnecessary to use such a high rate of application for the control of the smut disease in question. Injury in this case was further evident in a noticeably lowered vigor of the seedlings as compared with the checks and the other treatments.

Smut Resistance in Slender Wheat Grass

Smut Reaction of Wild Plants

Slender wheat grass, *Agropyron pauciflorum*, and several other species of *Agropyron* are native to this part of the North American continent. In Alberta, *Agropyron pauciflorum* is commonly found in the wild state in the central, western and northern parts of the province. Another closely related species, *Agropyron subsecundum* (Link) Hutch., bearded wheat grass, occurs abundantly in the same habitat, and types intermediate between the two, which are apparently natural hybrids, are frequently found. Although by artificial inoculation *Agropyron pauciflorum* has been found highly susceptible and *Agropyron subsecundum* moderately susceptible to the smut fungus from *Agropyron pauciflorum* (4, 6), wild plants of these species are very rarely observed to be smutted. It appeared possible therefore that there might be smut-resistant individuals among some of these wild plants, and if so, they might be used in the development of smut-resistant strains or varieties.

Consequently, opportunities being provided during the course of Plant Disease Survey trips in 1932–33, collections of seed of wild plants were made from different parts of Alberta. In most cases the collections were from plants typical of *Agropyron pauciflorum*, but in some instances as judged from the progenies of the plants, intermediate types between *Agropyron pauciflorum* and *Agropyron subsecundum* apparently were chosen.

Seed of the above collections of wild plants was artificially smutted with smut obtained from diseased stands of *Agropyron pauciflorum* growing at Edmonton. Each collection was assigned a number and sown separately in rows in the field at Edmonton in the summer of 1935. Most of the collections survived the winter and headed in 1936, when notes were taken

TABLE IV

Smut reaction of progenies of wild plants of *Agropyron pauciflorum* and intermediates between *Agropyron pauciflorum* and *Agropyron subsecundum*

Number of strain	Place collected	Per cent of smutted heads
I-35-4	Mundare	0.0
I-35-5	Bentley	16.0
I-35-8	Westlock	14.0
I-35-13	Vermilion	33.0
I-35-14	Hughenden	0.0
I-35-15	Lloydminster	0.0
I-35-16	Chauvin	0.0
I-35-17	Provost	0.0
I-35-18	Sedgewick	6.0
I-35-21	Lloydminster	1.5
I-35-22	Chauvin	21.0
I-35-1	Tofield	26.0
I-35-3	Colinton	50.0
I-35-6	Sylvan Lake	36.0
I-35-7	Edmonton	8.0
I-35-9	Barrhead	1.0
I-35-10	Legal	30.0
I-35-11	Fort Saskatchewan	0.0
I-35-19	Edmonton	0.0
I-35-20	Daysland	12.0
I-35-23	Ranfurly	0.0

on the percentage of smutted heads. The total number of heads in each of the progenies was counted and the number of smutted heads was recorded as a percentage of the total. The data on smut reaction of these are given in Table IV. Approximately one-half of them (listed first in the table above the horizontal line) proved quite typical of *Agropyron pauciflorum*, producing slender, awnless, bilateral heads. There were, of course, some variations in color, height, leafiness, habit of growth and other characters. The remainder appeared intermediate between *Agropyron pauciflorum* and *Agropyron subsecundum*. The majority of these intermediate types produced unilateral heads with short awns, and rather broad, dark green leaves.

It is evident that there are wide differences in smut reaction among the progenies of the wild plants listed in Table IV. Some are quite susceptible, but a considerable proportion appear to be immune or highly resistant to the collection of smut with which they were inoculated. Those which developed no smut in these tests are not necessarily to be considered immune to all strains of smut from *Agropyron pauciflorum*, but subsequent tests have indicated that most of them are highly resistant or immune to other collections of this smut, and hence might serve as parental material for breeding work in the development of resistant or immune varieties.

Smut Resistance of the Variety Fyra

In the first part of this paper, which dealt with seed treatment, mention was made of the fact that the first tests on the relative effectiveness of different fungicides in smut prevention yielded no results, owing to the failure of the checks to develop any smut. In these tests the variety Fyra, an improved variety of slender wheat grass developed at the University of Alberta, was used. No data on the smut reaction of this variety had previously been obtained. The seed treatment tests, however, indicated that it might be resistant, since the tests were made in three different years with the untreated checks replicated each year, and no smut developed in them. We have now tested this variety along with commercial nondescript lots of seed, with several collections of smut, and determined that it is highly resistant to, but not immune from smut. Stands from the commercial seed under the same conditions were badly smutted. It is therefore now possible to state that the variety Fyra, in addition to its other desirable qualities, possesses high smut resistance though not general immunity.

Discussion

The results of the studies here reported show that the common smut of slender wheat grass may be prevented by seed treatment with organic mercury dusts and by the use of disease-resistant strains of the grass.

The organic mercury dusts gave complete control at rates as low as one-half ounce per bushel, whereas copper carbonate dust at two ounces per bushel, failed to control the smut satisfactorily. The organic mercury dusts have certain advantages over the wet formaldehyde treatment which has

been recommended for the control of this smut, though the latter is effective in smut prevention. Treating several months ahead of seeding, for instance, would seem safe with the organic mercury dusts tested, if applied at the one-half ounce rate, since no appreciable reduction in viability was noted after storage of treated seed for one year.

The occurrence of high smut resistance or immunity among local wild plants of *Agropyron pauciflorum* and among types intermediate between *Agropyron pauciflorum* and *Agropyron subsecundum* is reported apparently for the first time. These resistant plants obviously could be used in combating this smut in another way, namely, by using them in the breeding of resistant varieties. The studies, however, also bring to light the fact that at least one improved smut-resistant variety already exists, namely, the variety Fyra, pure seed of which has been distributed for several years by the University of Alberta. It may, however, be possible to improve upon the resistance of this variety which, as has been noted, is not immune, by re-selection or by crossing it or other superior varieties with highly resistant or immune wild selections.

While the use of immune varieties may eventually do away with the necessity of seed treatment, it would seem advisable at present to continue treatment as an insurance against smut, even in varieties like Fyra. This is particularly important in crops grown for seed and especially so in a perennial crop like slender wheat grass, since a stand once infected remains so throughout its life.

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STUDIES ON *RHIZOCTONIA SOLANI* KÜHN.

IV. EFFECT OF SOIL TEMPERATURE AND MOISTURE ON VIRULENCE[1]

BY G. B. SANFORD[2]

Abstract

The effects of soil temperatures between 16° and 25° C., and of soil moisture content between 19 and 40% of the moisture-holding capacity, on the virulence and type of attack of *Rhizoctonia Solani* on young potato sprouts, were studied under controlled conditions and the results from 13 separate tests are discussed. The comparative growth rates of the pathogen on nutrient agar and in soil are outlined.

At 25° C. the disease diminished very abruptly. Between 23° and 16° C., the pathogen appeared equally virulent throughout the range of soil moisture mentioned. The fluctuations which occurred in separate tests were not definite or consistent enough to warrant a conclusion that the virulence is greater at 16° than at 23°, or that a dry soil is more or less favorable to it than a wet one.

In a fertile, steam sterilized loam, at medium moisture content, it required about ten days for the pathogen to grow as far as it did on the surface of a nutrient medium in four days. The growth rate at either 23° or 16° C. was slightly higher in a wet soil than in one of medium moisture content, but in a dry soil the rate was somewhat less at 23° than at 16° in a medium or wet soil. Even in a fairly dry soil (19% moisture-holding capacity) at 16° the growth of the pathogen covered a distance of 5 cm. in ten days, which would appear adequate for infection of young sprouts from a set bearing viable sclerotia.

The effort of the host to recover, by means of secondary and tertiary sprouts from the attacked primary sprout, was better in a wet soil than in a dry one at both 16° and 23° C. The best effort was in a wet soil at 23°. A distinction is made between the effects of soil moisture and temperature in stimulating growth of the host, and their effect on parasitism itself.

The remarkable tendency of the secondary sprouts to escape infection, regardless of soil temperature and soil moisture, is indicated. There was evidence that certain factors other than soil temperature and moisture may play an important role in the parasitism of *R. Solani*.

In a previous paper (13) of this series, it was demonstrated that the development of stem canker of potato during the first 30 days in May was very slight in some fields, but rather severe in others. This occurred in the same locality, despite the fact that sets from the same source, uniformly and heavily infested with sclerotia, were used in all experiments. That some of this erratic behavior among experiments in various fields each year may have been influenced by differences in soil moisture seemed possible, because, in the many different crop sequences involved, this factor naturally would not be very uniform. Also, no doubt, the temperature varied slightly from field to field in the same district, but available records indicate that the temperature factor was fairly uniform in most experiments, and at least well within the range for vigorous disease development during the short duration of the test. On the other hand, cases occurred in which absence of disease could not be accounted for by differences in either soil moisture or soil temperature.

The relation of temperature to the development of disease on potatoes by *R. Solani* has been discussed by a number of workers, but the factor of soil

[1] *Manuscript received March 5, 1938.*
Contribution No. 544 from the Division of Botany, Experimental Farms Branch, Department of Agriculture, Ottawa, Canada, co-operating with the Department of Field Crops, University of Alberta.

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moisture does not appear to have received sufficient study. Therefore, it seemed advisable at this stage to investigate, under controlled conditions, the possible relation of both factors indicated.

Literature Review

The work of Müller (7), Newton (8), Le Clerg (4), Wellman (15), Monteith and Dahl (6) and others indicates that the optimum temperature for growth of the fungus *R. Solani* on nutrient agar may vary from approximately 23° to 30° C., depending on the strain involved, and to some extent on the host to which each was pathogenic. The optimum for strains known to be pathogenic to the potato usually varied between 24° and 27°, with 25° perhaps the most common.

With regard to soil temperature, the conclusions of Richards (12) have special significance to the present study, and therefore may, with advantage, be reviewed more fully here. He obtained lesions on potato stems from 9° to 30° C., but observed that only at temperatures below 24° was *R. Solani* seriously parasitic. Injury to the cortex of young stems during the first six weeks was especially severe between 12° and 21°, but most severe at 18°. Greatest destruction of the growing tips of young sprouts occurred between 12° and 18°. But above 18° this type of injury became less and less, and disappeared entirely at about 21°. Apparently he thought that the more rapid growth of the shoots from 21° to 24° was an important factor in the escape of the growing tips from injury, but on the other hand he states: "The pathogenic power of the parasite in fact appeared to be so distinctly inhibited by soil temperatures above 21° as to render the fungus practically unimportant as a pathogen upon the potato above 24° C." These two phenomena, *viz.*, the growth of shoot and the pathogenic power of the fungus, will be discussed later.

Müller (7) obtained greater damage to the growing tips of the sprouts between 12° and 15° than from 18° to 21° C., and Gratz (3) reported no attack on potato stems between 22° and 25° C.

Definite experimental evidence on the effect of soil moisture is apparently very meagre. In the field experiments of Richards (12), in 1918 and 1919, the disease was more severe in the former year when the soil was dry and cool during early plantings than in 1919, when the soil was warmer and more moist. He apparently thought that the marked differences in disease observed could be explained satisfactorily on the basis of temperature. Balls (1), Müller (7) and Orton (9) were of the opinion that the disease was favored in an over-moist soil. According to Peyronel (11), a soil that fluctuates in moisture content between a dry and moist state, favors disease. Martin (5), from field observations, reported that greater damage to potatoes occurred in places where the soil was deficient in moisture than where it was normal. Peltier (10), in connection with stem rot of *Dianthus caryophyllus*, states, "The conditions under which all strains manifested their greatest parasitism were primarily a high temperature (above 88° F.) and a soil moisture content either too low or too high for best development of the plant."

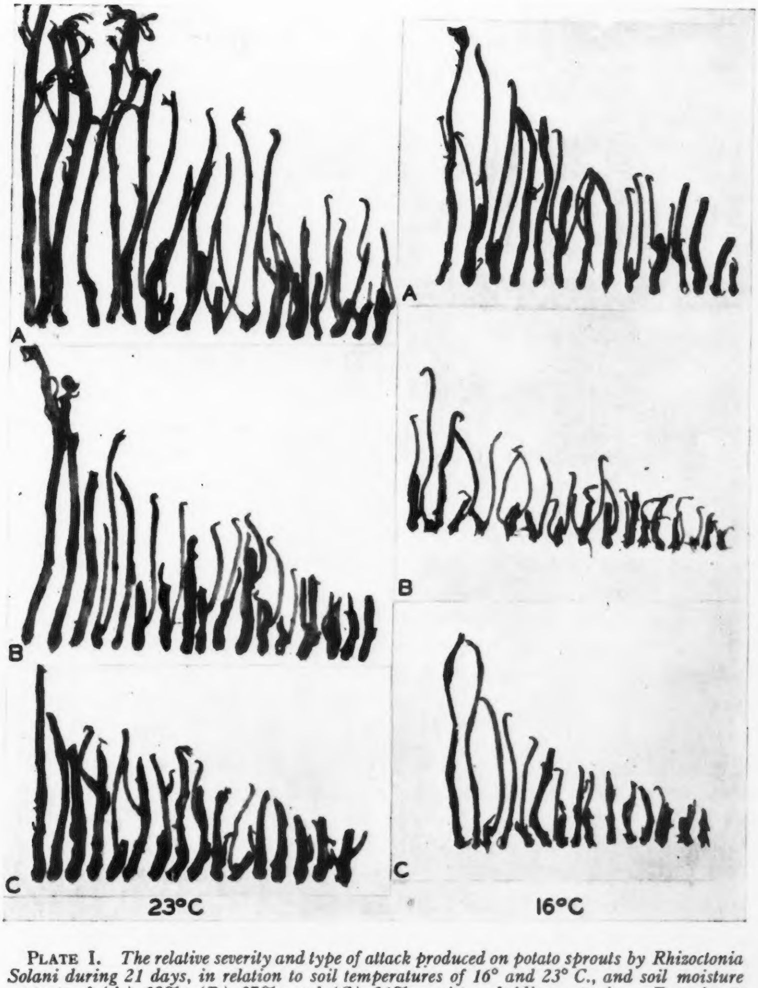

PLATE I. *The relative severity and type of attack produced on potato sprouts by Rhizoctonia Solani during 21 days, in relation to soil temperatures of 16° and 23° C., and soil moisture contents of (A), 38%; (B), 27%; and (C), 21%, moisture-holding capacity. Experiment 1, Table I.*

Materials and Methods

The method for determining the relative effect of soil temperature and soil moisture on the disease was very simple. Both factors were studied at the same time in parallel series. The only difference between the two series indicated was that of soil moisture and soil temperature. The general technique of preparing and infesting the soil was identical with that described in a previous paper (14). For instance, a natural, unsterilized, virgin prairie black loam was uniformly infested with the pathogen in the proportion of one part of inoculum to 15 parts of natural soil. This inoculum consisted of sterilized soil permeated with the pathogen. The containers were one-litre, wide mouth, Erlenmeyer flasks. A clean set (Early Ohio variety), of uniform size and surface, disinfected in acid mercuric chloride solution, was placed near the bottom of each flask and covered with the infested soil to a depth of five and one-half inches. The neck of each flask was then plugged with cotton. The sets were cut from tubers kept in cold storage at approximately 3° C.,* and were in the semi-dormant state when planted. This precaution was found to be very important in securing uniform results. There were 16 flasks, each containing one plant, in each unit of the experiment. Each test required 21 days from the date of planting. A numerical disease rating was given and other notes taken on each plant.

Soil Moisture

After the soil was infested, representative portions of it, sufficient for each test, were adjusted to dry, medium and wet soil moisture content (on the basis of the moisture-holding capacity of the soil) as required, and then put into the flasks. The percentage of soil moisture of each series varied only slightly from time to time when the experiment was repeated. Soil moisture determinations were made at the beginning and end of each test. These are indicated in Table I. The cotton plugs maintained the soil moisture to within approximately 1 to 3% of each initial value during the test, depending on the moisture content of the soil and the temperature. Thus, the fact that no further watering was necessary removed an important variable which exists when water is added to the soil from time to time.

Soil Temperature

The effect of temperatures from 16° to 23° was investigated because, as indicated in the literature review, there appears to be a difference of opinion regarding the influence of temperature within these limits on the degree and type of injury produced.

Results

Effect of Soil Moisture and Soil Temperature on the Disease

The results from 13 separate tests to determine the effect of soil moisture and soil temperature on the severity of the disease, are summarized in Table I. Two types of injury are described, *viz.*, "T" and "S". In the former, the primary sprouts are blighted soon after emergence from the sets and the

* *The Centigrade scale is used throughout this study.*

attack is severe. In the latter, the attack on the primary sprout is deferred and usually restricted to fairly small lateral lesions. The table shows which of these two types of injury prevailed, and also the percentage of plants which escaped entirely, because these data assist one to judge the relative severity of the disease. As a rule, the relation was close between a low percentage of plants that escaped and the "T" type of injury, and the severity of the attack. A disease rating of 50% or greater, combined with the "T" type of injury and few or no plants escaping, is certainly a very severe attack, and one which, on a different basis of estimate, might be as well expressed by 70% or a greater value. The fact that many plants sometimes escape without a single visible lesion, despite apparently optimum conditions for infection, while others are severely attacked, presents a baffling and difficult problem. Thus,

TABLE I

EFFECT OF SOIL MOISTURE AND SOIL TEMPERATURE ON DEGREE AND TYPE OF SPROUT CANKER OF POTATO CAUSED BY *Rhizoctonia Solani* IN SOIL ARTIFICIALLY INFESTED

Exp.	Moisture, %†	°C.	Injury		% Plants escaped	Isolate
			%	Type‡		
1	21	16	50	T	6	76
	27	16	60	T	0	
	38	16	60	T	0	
	21	23	60	T	0	
	27	23	57	T	0	
	38	23	45	T	25	
2	21	16	50	T	20	76
	29	16	63	T	0	
	39	16	51	T	0	
	21	23	39	T-S	20	
	29	23	52	T	0	
	39	23	50	T	0	
3	20	16	18	T	66	76
	39	16	3	T	94	
4	20	16	66	T	0	76
	38	16	66	T	6	
	19	23	18	S	60	
	36	23	6	S	31	
5	31	18	70	T	16	76
	39	18	38	T-S	20	76
	31	18	50	T	10	108
	39	18	40	S	7	108
6	19	18	16	S	75	76
	19	18	5	S	90	106
	27	18	2	S	85	76
	27	18	0		100	106
	36	18	20	S	40	76
	36	18	0		100	106
7	18	17	47	T	17	76
	39	17	20	T	67	
8	23	17	80	T	0	76
	39	17	53	T	0	
9	23	20	80	T	0	76
	42	20	25	S	10	
10	29	20	80	T	0	76
	28	25	10	S	40	
11	31	20	90	T	0	76
	29	25	41	T-S	0	
12						
ck.	32	16	50	T	13	76
A	32	16	10	S	40	
ck.	30	23	50	T	19	
A	30	23	55	T	0	
13						
ck.	33	16	31	T-S	50	76
A	33	16	12	S	50	
B	33	16	2	S	44	
C	33	16	5	S	66	
ck.	31	23	32	S-T	0	
A	31	23	56	T	10	
B	31	23	55	T	0	
C	31	23	36	T	41	

† *At conclusion of test, on basis of moisture-holding capacity of soil. During 21 days of the test about 1.5%, 2%, and up to 3% was lost from the dry, medium and wet series, respectively.*

‡ *"T" indicates prevalence of destruction of first sprout tip, and "S" prevalence of lesions on side of sprout.*

although a disease rating below, say 40%, is usually associated with the less virulent type of attack, it may be because only a few plants carried evidence of the "T" type of attack, and the others wholly escaped.

A point to be kept in mind is that all tests listed in Tables I and II were made in evenly and thoroughly infested natural soil for the duration of 21 days after the sets were planted. This method appeared adequate for the purpose of the study.

The year and month in which each of the 13 experiments listed in Table I were made are as follows: in 1937, October, Nos. 1 and 2; March, Nos. 3, 4 and 5; in 1936, March, No. 6; April, No. 7; May, Nos. 8, 9 and 10; July, No. 11; October, No. 12, and November, No. 13.

In Experiment 1, Table I, the attack appeared equally severe in the dry, medium and wet soils. The severe "T", or primary sprout type of attack, prevailed at both 16° and 23° C., and, with the exception of two units of the experiment, all the plants were affected. It is of interest to note that 25% of the plants in the soil at 38% moisture-holding capacity escaped attack, although the others were severely injured. Also, despite more rapid growth of the sprouts in the wet soil at 23°, and what might appear a greater tendency to recover, they were, on the whole, equally severely attacked. A careful examination of all the different series from Experiment 1, shown in Plate I, will confirm this analysis. In Experiment 2, a similar situation prevailed. The lower figures for the dry sets at 16° and 23° are accounted for by 20% of the plants escaping attack in each case.

The results of Experiment 3 appear to indicate more disease (18%) in the dry soil than (3%) in the wet one at 16°. In both dry and wet soils, the primary sprouts of affected plants were destroyed, but a large percentage of the plants in each case simply escaped. The results of Experiment 4 are practically identical at 16° in dry and wet soils, with the "T" type of injury prevailing, but at 23° the attack, which was of the "S" type and not severe, was definitely greater in the dry soil, despite the fact that twice as many plants escaped. In this case the injury was much more severe at 16° than at 23°; this is confirmed by the corresponding percentage of plants that escaped.

In Experiment 5, in which the soil temperature was 18°, and two isolates of contrasting pathogenicity employed, the attack of No. 76, a virulent isolate, was definitely greater at medium soil moisture (31% moisture-holding capacity) than in the wet soil (39%), and for isolate No. 108, also probably somewhat greater in the former soil. The results of Experiment 6, the soil temperature of which was 18°, indicate no definite difference in severity between the dry and wet soil. Practically no disease developed in the soil of medium moisture; for this no explanation is available. However, with *R. Solani*, variation of this kind may be expected, despite apparently rigid control.

In Experiment 7, in which the temperature was 17°, more disease occurred in the dry soil than in the wet one. However, it will be observed that the "T" type of injury prevailed in both cases, but about four times more plants

escaped in the wet soil. Experiment 8, at 17°, concluded the following month, indicated great severity of disease in a soil the moisture content of which was between dry and medium, *viz.*, 23% moisture-holding capacity, and 27% less injury in one of 39% moisture-holding capacity. No plants escaped, and the "T" type of injury prevailed. Another experiment (No. 9) at 20°, instead of 17°, again indicated practically maximum severity with the "T" type of injury at 23% soil moisture content, and 55% less disease with the "S" type of lesions at 42% soil moisture.

The results of Experiment 10 indicate that in a soil of medium moisture (28–29%) approximately maximum injury of "T" type occurred at 20°, while at 25° it was at least eight times less severe, with 40% of the plants escaping and an absence of the "T" type of injury. Experiment 11, made a month later, provides results which, for the medium moist soil, practically duplicate those of Experiment 10, although there was nearly one-half as much (40%) injury at 25° as there was at 20°, with an equal amount of plants affected with each type of injury.

Experiments 12 and 13 are similar and concern another phase of the general study in progress. The results are given here in connection with the temperature and moisture studies for the purpose of indicating the possible effect of other factors, such as nutrients, in modifying the severity of the disease at a given soil temperature or soil moisture. To Series A, B and C, of both experiments indicated, were added different amounts of sodium nitrate. The checks received none. The soil moisture was, in general, slightly above optimum, or between 30 and 33% moisture-holding capacity. In Experiment 12, the disease at 23° in the A series was five times more severe than in the corresponding series at 16°, and in Experiment 13, carried out one month later, it was again about five times greater at 23°. In Series B and C of Experiment 13, the increase was roughly 27 and 7 times, respectively, over that at 16°. In the controls of each experiment the disease was about equally severe at 16° and 23°. No particular significance should be attached to the greater severity of the disease in the checks of Experiment 12 than in those of Experiment 13, but it is important to note that the severity was practically the same in the checks at 16° and 23° in each of the two cases.

Table II provides additional data on the effect of soil temperatures of 17° and 23°. The soil moisture was approximately 29% moisture-holding capacity, or about optimum. With the exception of No. 76, the 25 random isolates indicated were tested at one time. Temperature was the only known variable. The apparent difference in pathogenic capability of this and other isolates (13 in all) is discussed in the previous paper (14).

Of the 26 isolates listed, nine produced more disease at 17°, and six of them (Nos. 1, 7, 10, 13, 14, and 15) caused more injury at 23°. The difference may not have been significant in all cases mentioned. Nine of the remaining 11 isolates were about equally pathogenic at 17° and 23°, and two did not produce disease. Possibly the "T" type of injury was more common at 17° than at 23°, but in certain cases both "T" and "S" types were about equally prevalent at both temperatures.

TABLE II

THE RELATIVE DISEASE INJURY TO POTATO SPROUTS, CAUSED BY VARIOUS RANDOM ISOLATES OF *Rhizoctonia Solani* FROM POTATO TUBERS, AT 17° AND 23° C. AND SOIL MOISTURE CONTENT APPROXIMATELY 27–29% MOISTURE-HOLDING CAPACITY.

Isolate	17° C.			23° C.			Isolate	17° C.			23° C.		
	Injury		% Plants escaped	Injury		% Plants escaped		Injury		% Plants escaped	Injury		% Plants escaped
	%	Type†		%	Type†			%	Type†		%	Type†	
1	41	T-S	25	*66*	T	0	14	8	T	81	*28*	S	31
2	*43*	S-T	12	32	S-T	31	15	26	T	50	*32*	S-T	31
3	*33*	T-S	25	7	S	81	16	*45*	T	25	36	T-S	19
4	11	S	62	12	S	62	17	1	S	81	0		100
5	0		100	0		100	18	*36*	T	31	10	S-T	81
6	*28*	S	6	18	S	31	19	*32*	T-S	31	24	T-S	50
7	7	S	75	*19*	S	25	20	2	S	81	0		100
8	27	T-S	44	31	S-T	38	21	*44*	T	19	26	S-T	50
9	0		100	0		100	22	10	T	62	10	S	56
10	0		100	*27*	S	31	23	5	S-T	81	4	T	88
11	*18*	S	31	7	S	81	24	*30*	T-S	44	10	S	75
12	0		100	2	S	88	25	6	S	81	6	S	94
13	16	S	62	*44*	T	6	76‡	60	T	0	59	T	0

† *"T" and "S" indicate relative prevalence of destruction of primary sprout, and lesions on side of stems, respectively.*

‡ *See Experiment 1, Table I.*

Growth Rate of Pathogen in Relation to Temperature and Moisture

It has frequently been assumed that an abundant and rapid growth of the pathogen has an important bearing on the development of the disease. In testing 133 isolates for pathogenicity to the potato it was observed (14) that some isolates characteristically made more abundant and quicker growth than others did. However, very frequently the severity of disease seemed to bear a negative relation rather than a positive one to abundant growth. But, according to the data just presented, the disease may develop to maximum severity at 16° and 17° C., and surprisingly well in the very dry soil, where less growth is expected.

On a Nutrient Medium

It was decided to compare, on a nutrient medium, the rate of growth of 12 representative isolates, six of which proved pathogenic to potato, and six of which did not. These isolates were incubated at 10°, 15°, 20° and 25° C. in Petri plates on potato-dextrose agar, and the daily rate of growth was measured during ten days. The growth of these isolates, based on the measurements from six plates during four days, is compared in Fig. 1. With certain exceptions, the data indicated that for the fungus to grow the same distance covered in four days at 25°, it would require slightly over five days at 20°, about six days at 16°, and ten days at 10°. However, pathogenic Isolates Nos. 76 and 20, and non-pathogenic Isolate No. 48, grew almost equally well at 20° and 25°. Also, certain isolates apparently were relatively more or less vigorous than others at a given temperature. This may explain why a more uniform agree-

ment with regard to optimum temperature for growth has not been reached by certain other investigators. There seems no doubt that the optimal point for the great majority of the isolates pathogenic to the potato is somewhat above 20°, and probably very near 25°. Some dissimilarity among isolates in this respect is to be expected.

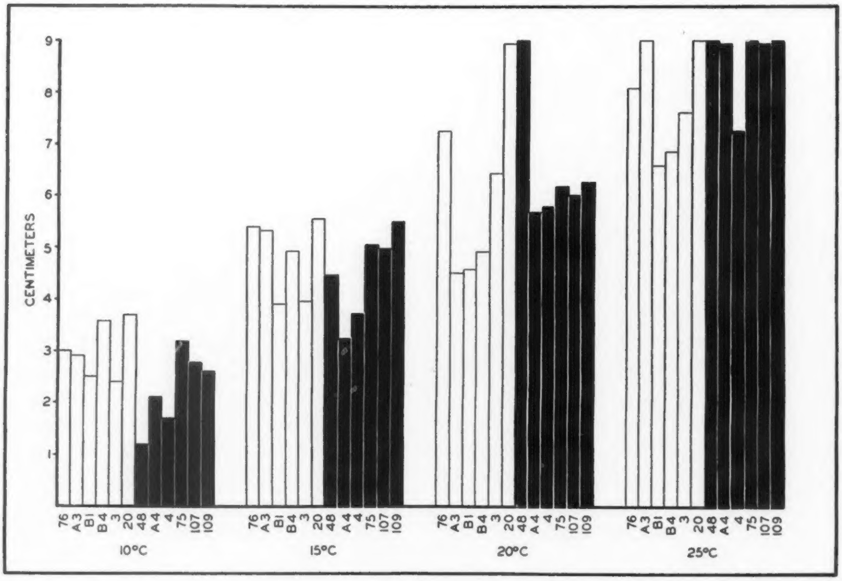

FIG. 1. *The relative growth rate during four days of 12 isolates of Rhizoctonia Solani on potato-dextrose agar at 10°, 15°, 20° and 25°C. The unshaded columns represent virulent isolates, and the shaded ones non-pathogenic isolates.*

Growth Rate of Pathogen in Soil

This was determined by measuring the daily growth of *R. Solani* in steam sterilized, black loam soil, described as Type 1 in the previous paper (14). The soil, adjusted to approximately 20% (dry), 30% (medium), or 39% (wet), on the basis of moisture-holding capacity, was placed in large test tubes, which were loosely plugged and steam sterilized, after which they were inoculated and incubated at 16° and 23°. There were ten soil tubes in each test. The average rate of growth for each isolate during ten days is charted in Fig. 2.

The rate of growth in the wet soils at 23°, and also at 16°, slightly exceeded that in the corresponding soils of medium moisture content. Slowest growth occurred in the dry soil at both temperatures. Evidently a moisture content of 20% moisture-holding capacity, which is still sufficient for fair growth of the potato plant, was more important in determining the growth rate of the pathogen than the temperature factor itself between 16° and 23°.

Discussion

We may now examine the effect on the disease of soil moisture and soil temperature in the following connections, *viz.*, on the growth rate of *R. Solani;* on the severity and type of attack on potato shoots; and, finally, on the ability of the host to recover from attack.

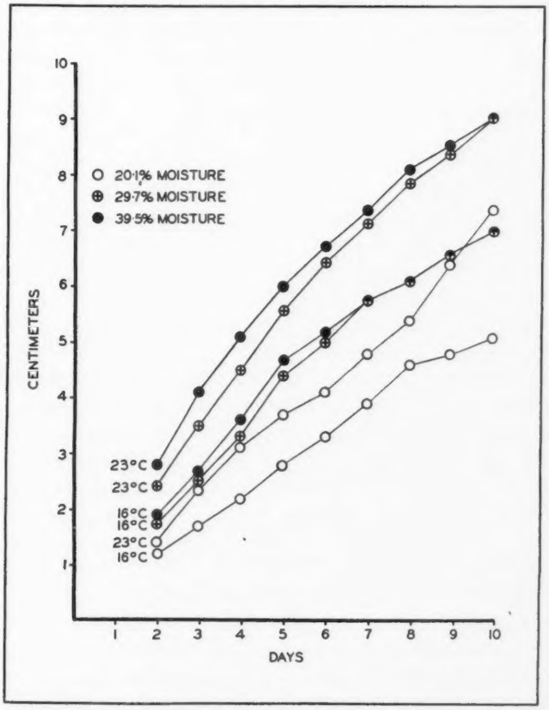

FIG. 2. *The relative growth rate of Rhizoctonia Solani during ten days in sterilized soil at 16° and 23° C., and soil moisture contents of 20.1%, 29.7%, and 39.5%.*

The growth rate of *R. Solani* in a soil is modified by temperature and very greatly by the moisture content. The optimum temperature for nine of the 12 isolates tested seemed near 25°, but three of them appeared to grow as well at 20° as at 25°. Therefore, it is obvious that the optimum temperature for *R. Solani* cannot be determined from a single isolate. Again, it is characteristic of some isolates to grow slowly, while others grow quickly and abundantly. In dry soils the latter type would seem more effective pathogens than the former, if the limiting factor is only a matter of distance between the host and pathogen. On the contrary, these inherent differences in growth rate among isolates, although effective in controlled experiments, may easily be of little or no practical importance under field conditions. It has been pointed out previously in these studies that the usual differences in growth

rate which occur at temperatures of 23° and 16° in a moist soil are practically nullified if the soil is dry. This is significant because it indicates that a dry osil of 19% moisture-holding capacity is more important in reducing the growth rate, and therefore chances of infection, than the low temperature of 16°.

The evidence regarding the effect of soil moisture on the severity of disease and type of injury (Tables I and II) indicates that while there may be a slight tendency for greater severity in a soil deficient in moisture than in one of moderate or high moisture content, the difference was not definite and constant enough to warrant a final conclusion. However, it is certain that, as a rule, the disease can attain maximum severity on young potato sprouts in an unsterilized soil artificially infested with the pathogen at soil moisture contents ranging between a fairly dry state and a fairly wet condition, *viz.*, 19% and 40% moisture-holding capacity, respectively. The effect of rather limited soil moisture *versus* an adequate supply, on recovery of the host from the first attack by means of secondary sprouts, is discussed in another paragraph.

Expected differences with regard to the differential effect on disease severity and type of attack, of temperatures between 16° and 23°, inclusive, were not obtained in these studies. At 25° the severity abruptly decreased, but at 23° the pathogen appeared as frequently virulent as at 16°, 18° or 20°, and the type of injury was not essentially different. Apparently, under the conditions of the test striking and consistent differences are not to be expected; otherwise at least a tendency in certain directions would have been indicated. Perhaps under other conditions the differential effect of temperatures between 16° and 23° could be demonstrated, but the present studies suggest the advisability of at least several tests for a decision.

Richards (12) believed that the "T" type of injury was favored by soil temperatures of 18° and somewhat lower, and the "S" type by temperatures near 23°. The data of this paper indicate that either type of injury could occur to the practical exclusion of the other at both 23° and 16°. The prevalence of the "T" type of injury at any temperature merely indicates that the environmental factors favored a high degree of virulence of the pathogen on the one hand, or the susceptibility of the host on the other. Likewise the "S" type is an indication of weak parasitism.

Undoubtedly there are other factors, besides temperature and moisture, which play very important roles in the parasitism of *R. Solani* to the potato. Whether these affect the pathogen or the host, or both, is not clear. Certain incomplete evidence at hand suggests that the young host sprout, as affected by storage conditions, may be more susceptible at one time than another. Again, the pathogen, in the presence of certain nutrients, as, for example, sodium nitrate, produced more disease at 23° than at 16° (Experiments Nos. 12 and 13, Table I). Also, greater parasitism was exhibited in an infertile podsol soil than in a fertile organic loam (14).

Finally, there is the question of growth rate of the host in relation to the type of attack and the degree of injury, suggested by Richards (12). Given equal soil moisture, the emergence of the primary sprout requires less time, and its subsequent growth is considerably better at 23° than at 16°. The

greatest contrast in growth rate is found between a wet soil at 23° and a dry one at 16°. Thus, if the disease tends to be more severe at the lower temperature range, as indicated by Richards (12) and Dana (2), and if increased disease severity is really associated with slow growth, then a dry soil at low temperature should favor the attack most. But these studies have failed to demonstrate a constant and definite tendency in this respect.

The effort at recovery by means of secondary sprouts from severely lesioned primary sprouts was a characteristic feature. Naturally they were larger at 23° and also grew more quickly than at 16°. In soils of wet and medium moisture their number was not noticeably different at these temperatures but in dry soil the number tended to be limited to one, particularly at 16° (Plate I). Thus, if, toward the end of the first 21 days after planting, these sprouts are an important factor in recovery, less progress is made in a dry soil at a low temperature. But this phenomenon, although economically valuable, should not be confused with a consideration of parasitism itself. However, it is both important and interesting that a high percentage of these secondary sprouts appear to possess a remarkable degree of resistance, notwithstanding the primary sprouts were very susceptible and severely attacked under apparently identical conditions. Their escape seems to be equally common at 16° and 23° (Plate I).

A general conclusion from this study is that, heretofore, probably too much emphasis has been given to the effect of temperature between 16° and 23°, and not enough attention to other factors which affect the ability of the pathogen to attack, and the host to resist.

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AGRICULTURAL METEOROLOGY: CORRELATION OF MONTHLY PRECIPITATION IN CENTRAL AND SOUTHERN ALBERTA AND SASKATCHEWAN WITH LATITUDE, LONGITUDE AND ALTITUDE[1]

BY J. W. HOPKINS[2]

Abstract

The linear partial regression coefficients of the 19-year average (1917–1935) monthly precipitation recorded at 42 points in central and southern Alberta on latitude, longitude and altitude were determined for each month of the year. The correlation of precipitation with these co-ordinates, although statistically significant, was only moderate. Some improvement was effected by inclusion of the quadratic term in longitude, but even so, more than 50% of the inter-station variance of the 19-year precipitation averages for most months remained in the form of residual deviations. Observations for individual years were even less amenable to graduation. Consequently, a given number of meteorological stations would provide a much less complete specification of precipitation than of air temperature (the subject of a parallel previous study) within the area considered.

In a previous communication (3), the writer described the correlation of monthly mean air temperature with the latitude, longitude and altitude of meteorological stations in central and southern Alberta and Saskatchewan, and indicated the significance of the correlations found in connection with a criterion of the adequacy of the number of meteorological stations within an area, proposed by Irwin (4). The present paper gives the results of a parallel study of precipitation statistics for stations in the same districts. As before, two series of data are considered, *(a)* long-term or climatological averages, and *(b)* records for an individual year.

Data

For the climatological series, it was planned to use the precipitation records for the set of 43 stations adopted in the preceding study of air temperature, as this would have reduced to a minimum the further arithmetical work required in the calculation of the regression coefficients. When, however, the available monthly totals of precipitation for the 19-year period 1917–1935 were extracted from the Monthly Record published by the Meteorological Service of Canada (5), it was found that there were numerous discontinuities in the data for Shaunavon, Saskatchewan, and this station had in consequence to be discarded. Table I shows the 19-year average of precipitation, expressed as inches of rain (10 in. snow = 1 in. rain), for each month of the year at the remaining 42 stations. (Some substitutions of observations at neighboring points were necessary in the earlier years). The mean values given at the foot of this table show a pronounced seasonal trend, the average precipitation

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TABLE I

AVERAGE MONTHLY PRECIPITATION (AS INCHES OF RAIN), 1917–1935

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
ALBERTA												
Alix	0.82	0.64	1.12	1.23	1.79	2.56	2.26	1.93	1.41	0.74	0.82	0.81
Bassano	.49	.48	.64	1.36	1.91	1.85	1.85	1.17	1.21	.55	.58	.62
Calgary	.47	.59	1.03	1.41	1.54	3.20	2.31	1.92	1.84	.81	.71	.76
Calmar	.70	.61	.92	1.20	2.36	3.16	2.68	2.71	1.55	.84	.80	.84
Edmonton	.99	.66	.97	1.06	1.90	2.87	2.99	2.29	1.17	.80	.84	.97
Gleichen	.62	.66	.77	1.33	1.46	2.19	2.14	1.50	1.28	.65	.69	.76
Harmattan	.59	.52	.96	1.36	2.07	2.97	2.58	2.78	1.91	.74	.65	.68
High River	.92	.97	1.82	2.01	1.87	3.55	1.91	2.12	1.75	1.39	1.09	1.05
Hillsdown	.72	.57	.96	1.46	1.53	2.13	1.82	1.57	1.50	.72	.71	.76
Lacombe	.63	.61	.83	1.45	2.03	2.77	2.51	2.34	1.70	.78	.77	.83
Lethbridge	.50	.66	1.07	1.58	1.76	2.38	1.51	1.37	1.76	1.01	.85	.83
Lundbreck	.76	.92	1.45	1.40	1.59	3.03	1.70	1.72	1.25	1.00	1.01	1.09
Macleod	.64	.67	1.15	1.42	1.66	2.71	1.62	1.45	1.75	1.07	.86	.78
Medicine Hat	.67	.40	.69	1.12	1.28	2.09	1.51	1.34	1.28	.65	.56	.85
Olds	.59	.67	.79	1.43	2.01	2.99	2.27	2.52	1.66	.69	.58	.59
Pekisko	1.05	.87	1.59	2.26	2.48	3.70	1.97	2.43	2.50	2.52	1.32	1.22
Perbeck	.51	.36	.67	.98	1.81	2.80	2.29	1.74	1.58	.54	.45	.56
Ranfurly	.90	.83	1.17	.98	1.85	2.61	2.50	2.34	1.26	.89	.75	.86
Strathmore	.39	.60	.64	1.29	1.88	2.85	1.77	1.94	1.60	.79	.72	.53
SASKATCHEWAN												
Anglia	.56	.35	.65	.83	1.20	2.14	1.56	1.43	1.03	.71	.47	.43
Battleford	.61	.37	.48	.98	1.29	2.44	1.78	1.71	1.41	.73	.44	.53
Chaplin	.55	.43	.68	.89	1.69	2.77	1.80	1.79	1.15	.80	.52	.45
Ft. Qu'Appelle	.73	.52	.79	.79	1.49	2.75	2.09	1.72	1.34	.98	.80	.53
Indian Head	.83	.62	1.24	.99	1.76	3.08	2.35	1.78	1.55	1.16	1.03	.72
Kamsack	.98	.60	.78	.77	1.41	3.14	2.50	2.12	1.42	.91	.64	.67
Klintonel	.87	.79	1.04	1.47	1.89	3.08	2.04	1.48	1.37	.80	.72	.88
Melfort	.65	.40	.69	.75	1.41	2.66	2.13	2.21	2.19	1.03	.77	.54
Moose Jaw	.65	.58	.79	.91	1.68	3.02	1.67	1.90	1.50	.93	.77	.69
Muenster	.62	.33	.72	.82	1.56	3.48	2.41	1.76	1.65	.89	.47	.58
Nashlyn	.39	.39	.45	.94	1.29	2.13	1.57	.95	.96	.39	.52	.50
Pilger	.73	.52	1.01	.86	1.31	3.12	2.22	1.68	1.63	.84	.58	.63
Prince Albert	.61	.42	.90	1.08	1.40	3.06	1.95	2.18	1.73	.90	.66	.67
Qu'Appelle	.87	.62	1.18	1.32	1.82	3.37	2.28	1.89	1.64	1.29	1.08	.68
Regina	.66	.42	.78	.79	1.55	3.08	2.03	1.65	1.28	.98	.80	.48
Rosthern	.62	.45	.91	.98	1.33	2.61	2.31	1.78	1.51	.94	.58	.61
St. Walburg	.76	.53	.71	.98	1.33	2.57	2.60	1.97	1.30	.64	.59	.58
Saskatoon	.66	.48	.84	1.03	1.22	2.76	2.33	1.70	1.52	.97	.65	.53
Scott	.65	.55	.74	1.00	1.16	2.26	1.96	1.52	1.24	.60	.56	.67
Swift Current	.73	.50	.67	.93	1.65	2.94	2.10	1.95	1.34	.83	.54	.64
Waseca	.82	.65	.71	1.11	1.22	2.37	1.81	1.76	1.42	.61	.77	.61
Whitewood	.92	.49	.84	1.20	1.75	3.23	2.24	1.78	1.66	1.23	.97	.68
Yellow Grass	.65	.57	.77	1.06	1.74	3.05	2.06	1.74	1.52	.90	.82	.59
Mean	0.69	0.57	0.90	1.16	1.64	2.80	2.09	1.85	1.51	0.89	0.73	0.70
Standard deviation	.16	.15	.28	.32	.31	.43	.35	.39	.29	.33	.19	.17
Standard deviation, %	23	26	31	28	19	15	17	21	19	37	26	24

for the 42 stations being greatest in June and least in February. Absolute variation between stations in the 19-year average, as indicated by the standard deviation, is likewise greatest in summer and least in winter, but the relative variability tends to be greatest in winter.

Analysis of Climatological Series

The latitude, longitude and altitude of the 42 meteorological stations may be found in Table I of the preceding paper (3), and accordingly are not repeated here. By using the values given there, the Normal Equations to determine the linear regression coefficients b_1, b_2, and b_3 of January precipitation on latitude, longitude and altitude were found to be

$$\begin{aligned} 239{,}747\, b_1 + 43{,}485\, b_2 - 982{,}441\, b_3 &= 61.92 \\ 43{,}485\, b_1 + 2{,}452{,}267\, b_2 + 5{,}885{,}396\, b_3 &= -255.06 \\ -982{,}441\, b_1 + 5{,}885{,}396\, b_2 + 24{,}014{,}360\, b_3 &= -82.90 \end{aligned}$$

the left-hand side differing slightly from that of the corresponding equations in the earlier paper, owing to the omission of Shaunavon. The equations for the other 11 months differed from the foregoing only in the substitution on the right-hand side of the successive trios of products:

−85.46	−149.70	−286.84	−126.85	−138.11	634.38
697.47	833.09	2116.83	1409.49	−821.78	−122.22
2881.63	4276.18	8222.90	5389.18	2097.71	−1886.01
594.02	34.00	−244.46	−178.67	−71.25	
768.67	346.51	−213.23	189.58	925.35	
1236.36	2839.55	2967.72	2234.59	3266.46	

Solution of these 12 sets of equations was again effected by means of Fisher's inverse matrix method (1, Sec. 29), the multipliers being, in millionths,

	$c_{.1}$	$c_{.2}$	$c_{.3}$
$c_{1.}$	8.365264	−2.354635	0.919298
$c_{2.}$		1.652989	−0.501441
$c_{3.}$			0.202143

By the use of these multipliers, the regression coefficients and their respective standard errors listed in Table II were arrived at. Table III shows the

TABLE II

PARTIAL REGRESSION COEFFICIENTS OF 19-YEAR AVERAGE (1917–1935) MONTHLY PRECIPITATION (EXPRESSED AS INCHES OF RAIN) ON LATITUDE, LONGITUDE AND ALTITUDE OF METEOROLOGICAL STATIONS

Month	Partial regression coefficient of precipitation on		
	Latitude (1/100's in. per 10′ N.)	Longitude (1/100's in. per 10′ W.)	Altitude (1/100's in. per 100 ft.)
January	+1.04 ± .43	−0.53 ± .19	+1.68 ± .67
February	+ .29 ± .36	− .09 ± .16	+1.54 ± .56
March	+ .72 ± .71	− .41 ± .32	+3.09 ± 1.10
April	+ .18 ± .55	+ .05 ± .24	+3.37 ± .86
May	+ .57 ± .76	− .07 ± .34	+2.66 ± 1.19
June	+2.71 ± 1.02	−2.08 ± .45	+7.09 ± 1.58
July	+3.86 ± .81	− .75 ± .36	+2.63 ± 1.26
August	+4.30 ± .91	− .75 ± .40	+4.10 ± 1.41
September	+2.08 ± .74	− .93 ± .33	+4.31 ± 1.15
October	+1.19 ± .81	−1.26 ± .36	+4.82 ± 1.27
November	+ .11 ± .51	− .39 ± .23	+1.92 ± .79
December	+ .23 ± .42	+ .05 ± .19	+1.31 ± .65

coefficient of multiple correlation R between precipitation and latitude, longitude and altitude for each of the 12 months, and also the residual standard deviation of the actual 19-year station averages from the graduated values of the regression equation for each month.

It may be noted at once that inter-station differences in the 19-year averages of monthly precipitation are much less closely representable by linear functions of the co-ordinates of position and altitude than were the corresponding differences in air temperature (3). However, the variation between stations in respect to precipitation is not entirely unsystematic or non-linear. Thus the occurrence of 12 coefficients of like sign, as in the second column of Table II, from 12 uncorrelated series is an event having a random probability of only 1 in 2048, from which it may be inferred with reasonable certainty that there is a definite tendency for the amount of precipitation to increase from south to north. Similarly, the 19-year average decreases somewhat from east to west, after allowance is made for differences in latitude and altitude. In both cases, the maximum trends, and indeed almost the only ones of any significance, occur during the period June-October. Of the three co-ordinates, however, that of altitude is most consistently associated with differences in precipitation, the regression coefficients being again all positive (*i.e.*, precipitation increasing with altitude), and 11 of the 12 being individually statistically significant. Nevertheless, even when all three factors are taken into account, the multiple correlation coefficients shown in Table III are generally very moderate, and in only a few months is the standard deviation appreciably reduced by the linear graduation effected. This is in marked contrast to the results previously obtained in the analysis of the corresponding temperature data (3).

TABLE III

MULTIPLE CORRELATION COEFFICIENT (R) BETWEEN 19-YEAR AVERAGE (1917–1935) PRECIPITATION AND LATITUDE, LONGITUDE AND ALTITUDE OF METEOROLOGICAL STATIONS, AND RESIDUAL STANDARD DEVIATION (s), BY MONTHS

Month	R	s, in.
January	0.43	0.15
February	.61	.13
March	.52	.25
April	.82	.19
May	.57	.26
June	.61	.35
July	.64	.28
August	.63	.31
September	.53	.26
October	.56	.28
November	.47	.18
December	.61	.14

When the residual deviations of the actual from the graduated values of precipitation were being computed, it was noted that certain stations tended to have a majority of negative, and others to have a majority of positive deviations. The algebraic sums of the deviations for each station for the separate six-month periods April-September and October-March were entered accordingly upon maps of central and southern Alberta and Saskatchewan. In this way, it was found that the positive deviations tended to be concentrated in the eastern and western quarters of the area, whereas the

central half had a predominance of negative deviations. This, of course, suggested that even after allowing for differences in latitude and altitude, precipitation did not, on the average, increase steadily from east to west, but was at a minimum somewhere in the central region. It seemed worthwhile, therefore, to ascertain whether inclusion of the quadratic term in longitude in the regression equation would lead to a significant improvement in graduation.

This necessitated the calculation of a number of additional sums of squares and products, after which the Normal Equations to determine the regression coefficients b_1, b_2, b_3, and b_4 of January precipitation on latitude, longitude, altitude and the square of longitude ($\times\ 10^{-2}$) were found to be:

$$\begin{aligned}
239{,}747\, b_1 + 43{,}485\, b_2 - 982{,}441\, b_3 + 193{,}308\, b_4 &= 61.92\\
43{,}485\, b_1 + 2{,}452{,}267\, b_2 + 5{,}885{,}396\, b_3 + 23{,}252{,}993\, b_4 &= -255.06\\
-982{,}441\, b_1 + 5{,}885{,}396\, b_2 + 24{,}014{,}360\, b_3 + 58{,}644{,}655\, b_4 &= -82.90\\
193{,}308\, b_1 + 23{,}252{,}993\, b_2 + 58{,}644{,}655\, b_3 + 228{,}141{,}509\, b_4 &= -1456.67
\end{aligned}$$

the equations for the other 11 months being again derived from these by the substitution on the right-hand side of the successive quartets of sums of products:

−85.46	−149.70	−286.84	−126.85	−138.11	634.38
697.47	833.09	2116.83	1409.49	−821.78	−122.22
2881.63	4276.18	8222.90	5389.18	2097.71	−1886.01
7480.39	9898.89	21773.53	16028.56	−3707.52	1011.22

594.02	34.00	−244.46	−178.67	−71.25
768.67	346.51	−213.23	189.58	925.35
1236.36	2839.55	2967.72	2234.59	3266.46
10274.82	5711.97	558.47	3683.56	9766.05

TABLE IV

PARTIAL REGRESSION COEFFICIENTS OF MEAN MONTHLY PRECIPITATION (1917–1935) AT METEOROLOGICAL STATIONS IN CENTRAL AND SOUTHERN ALBERTA AND SASKATCHEWAN ON LATITUDE (b_1), LONGITUDE (b_2), ALTITUDE (b_3) AND THE SQUARE OF LONGITUDE (b_4)

Month	b_1, 1/100's in. per 10′ N.	b_2, 1/100's in. per 10′ W.	b_3, 1/100's in. per 100 ft.	b_4, 1/100's in. per (10′ W.)^2
January	0.96	−1.43	1.28	.0105
February	.24	− .72	1.27	.0073
March	.57	−2.04	2.39	.0189
April	.09	− .94	2.94	.0115
May	.34	−2.65	1.54	.0301
June	2.40	−5.46	5.62	.0394
July	3.60	−3.63	1.39	.0335
August	3.98	−4.25	2.59	.0408
September	1.89	−3.03	3.40	.0245
October	1.02	−3.13	4.01	.0217
November	−.04	−2.12	1.17	.0201
December	.15	− .79	.94	.0099

TABLE V

ANALYSIS OF VARIANCE, REGRESSION OF MEAN MONTHLY PRECIPITATION (1917–1935) AT METEOROLOGICAL STATIONS IN CENTRAL AND SOUTHERN ALBERTA AND SASKATCHEWAN ON LATITUDE, LONGITUDE AND ALTITUDE

Variance due to	Degrees of freedom	January		February		March		April		May		June	
		Sum of squares	Mean square	Sum of squares	Mean square	Sum of squares	Mean square	Sum of squares	Mean square	Sum of squares	Mean square	Sum of squares	Mean square
Longitude (quadratic)	1	0.0752	0.0752	0.0359	0.0359	0.2417	0.2417*	0.0899	0.0899	0.6116	0.6116**	1.0502	1.0502**
Latitude, longitude and altitude (linear)	3	0.1847	0.0616*	0.3560	0.1187**	0.8687	0.2896**	2.8295	0.9432**	1.2566	0.4189**	2.8270	0.9423**
Residual	37	0.7629	0.0206	0.5589	0.0151	2.0418	0.0552	1.2887	0.0348	2.0365	0.0551	3.6445	0.0985
Total	41	1.0228	–	0.9508	–	3.1522	–	4.2081	–	3.9047	–	7.5217	–

Variance due to	Degrees of freedom	July		August		September		October		November		December	
		Sum of squares	Mean square	Sum of squares	Mean square	Sum of squares	Mean square	Sum of squares	Mean square	Sum of squares	Mean square	Sum of squares	Mean square
Longitude (quadratic)	1	0.7605	0.7605**	1.1278	1.1278**	0.4059	0.4059*	0.3200	0.3200*	0.2752	0.2752**	0.0664	0.0664
Latitude, longitude and altitude (linear)	3	2.0444	0.6815**	2.4844	0.8281**	0.9733	0.3244**	1.4107	0.4702**	0.3364	0.1121**	0.4659	0.1553**
Residual	37	2.2257	0.0602	2.6330	0.0712	2.0942	0.0566	2.6916	0.0727	0.9130	0.0247	0.7216	0.0195
Total	41	5.0306	–	6.2452	–	3.4734	–	4.4223	–	1.5246	–	1.2539	–

* *Exceeds mean square residual, 5% level of significance.*
** *Exceeds mean square residual, 1% level of significance.*

Proceeding as before, the matrix of multipliers for the solution of these 12 sets of equations was found to be, in millionths:

	$c_{.1}$	$c_{.2}$	$c_{.3}$	$c_{.4}$
$c_{1.}$	8.45445	−1.37015	0.96220	−0.11481
$c_{2.}$		12.52292	−0.02949	−1.26764
$c_{3.}$			0.22263	−0.05504
$c_{4.}$				0.14783

These gave the partial regression coefficients of mean monthly precipitation on latitude, longitude, altitude and the square of longitude ($\times\ 10^{-2}$) shown in Table IV.

The improvement in graduation resulting from the inclusion of the quadratic term may be determined from the additional variance accounted for. This is indicated in Table V. For all 12 months the variance accounted for by the additional term exceeds the mean square residual, so that the results as a whole are certainly consistent with the supposition of a non-linear element in the longitudinal variation of precipitation. Considering the data for each month individually, however, it is seen that during the winter months, when the inter-station variation in precipitation is least, the increase in precision is not significant.

The regression coefficients for altitude in Table IV are again all positive, indicating that, on the average, precipitation increases with elevation. There is likewise a definite tendency for precipitation to increase from south to north, but this is much more pronounced in the summer than in the winter months. The amounts actually received increase, on the whole, from east to west, but it was indicated in Table II that this was more than accounted for by differences in altitude, so that after allowing for this factor the linear regression of precipitation on west longitude was either insignificant or negative. The linear coefficients b_2 of Table IV are again uniformly negative, but the quadratic coefficients b_4 are all positive, indicating that the longitudinal variation passes through a minimum somewhere in the central part of the region. The actual longitude λ corresponding to the minimum of the longitudinal graduation was readily computed by equating the partial derivative of the regression equation for each month with respect to longitude, namely $b_2 + 2/10\lambda b_4$, to zero. The

TABLE VI

MULTIPLE CORRELATION COEFFICIENT (R) BETWEEN MEAN PRECIPITATION, 1917–1935, AND LATITUDE, LONGITUDE AND ALTITUDE, AND RESIDUAL DEVIATION (s), BY MONTHS

Month	R	s, inches	s, per cent
January	0.50	0.14	21
February	.64	.12	22
March	.59	.24	26
April	.83	.19	16
May	.69	.24	14
June	.72	.31	11
July	.75	.25	12
August	.76	.27	14
September	.63	.24	16
October	.63	.27	30
November	.63	.16	22
December	.65	.14	20

twelve values thus obtained fluctuated irregularly about a mean of 110° 9′ (*i.e.*, the meridian passing about 30 miles east of Medicine Hat), with no clear indication of systematic seasonal variation.

Table VI shows for each month the multiple correlation coefficient R between mean monthly precipitation and latitude, longitude (quadratic) and altitude, and the residual deviation s of the actual from the graduated values both in inches of rain and as a percentage of the 19-year 42-station mean. Even after the inclusion of the quadratic term, the agreement between the actual and graduated values leaves a good deal to be desired, more than 50% of the inter-station variance of the 19-year averages for most months remaining in the form of residual deviations. A given number of meteorological stations would thus provide a much less complete specification of precipitation than of air temperature within the area considered.

Results for Individual Years

As in the case of air temperature (3), when the precipitation during any one month of a single year, rather than the monthly average for the 19-year period, is considered, further variation may arise from two sources. (i) Over the area as a whole, the precipitation of the month in question may be above or below the climatological average. (ii) Local variations, which tend to offset each other as the number of years' records increases, will be more pronounced. Annual differences of Type (i), in so far as they affect all stations equally, need not increase the residual standard deviation, since they require only an adjustment in the constant term of the regression equation. Irregular local variations, on the other hand, will, of course, result in greater discrepancies between the observed and graduated values.

The actual extent of such effects in the data for the months of January and July was investigated by the analysis of variance procedure (1). In each case, the total variance of the 19 × 42 monthly totals of precipitation was subdivided into portions due to (i) differences between the 19-year averages of the 42 individual stations; (ii) differences between the 42-station averages of the 19 individual years; and (iii) residual irregular variation. The results of these computations are shown in Table VII.

TABLE VII

ANALYSIS OF VARIANCE OF JANUARY AND JULY PRECIPITATION (TOTAL INCHES OF RAIN) AT METEOROLOGICAL STATIONS IN CENTRAL AND SOUTHERN ALBERTA AND SASKATCHEWAN, 1917–1935

Source of variation	Degrees of freedom	January		July	
		Sum of squares	Mean square	Sum of squares	Mean square
Between station means	41	19.5932	.4779**	95.5082	2.3295**
Between annual means	18	73.6029	4.0891**	578.3304	32.1295**
Residual	738	100.0325	.1355	872.1397	1.1818
Total	797	193.2286	—	1545.9783	—

** *Exceeds mean square residual, 1% level of significance.*

The mean squares between stations and between years for both months significantly exceed the mean square residual. Differences between the 19-year means for individual stations account for 10.1% of the total January variance, differences between the 42-station averages for individual years account for 38.1%, and 51.8% is attributable to local variation within years. The corresponding figures for July are 6.2, 37.4 and 56.4%, so that although the intra-annual correlation is statistically quite significant, there remains, nevertheless, in both cases an appreciable amount of residual local variation.

Actually, of course, a certain proportion of the observed differences between both station and year averages would be expected to arise from chance combinations of these random local fluctuations. If the true residual, between year and between station variances are denoted by σ_1^2, σ_2^2, and σ_3^2, then the observed residual mean squares s_1^2 of Table VII are direct statistical estimates of σ_1^2 for January and July, but the observed s_2^2 and s_3^2 should be equated to $(42\sigma_2^2 + \sigma_1^2)$ and $(19\sigma_3^2 + \sigma_1^2)$ respectively. Substituting s_1^2 for σ_1^2, the estimates of σ_2^2 and σ_3^2 deduced are 0.09413 and 0.01802 for January, and 0.7369 and 0.06041 for July, the corresponding standard deviations being 0.31 and 0.13, and 0.86 and 0.25 inches. For both months, therefore, the variation between year averages is about three times as great as that between station averages.

When the foregoing residual variances s_1^2, ascribable to irregular local variation within years, were added to the mean square deviation of the 19-year station averages from the graduation formulas of the preceding section, standard deviations of 0.39 inches for January and 1.12 inches for July were obtained. These, which are respectively three and four times the corresponding values in Table VI, indicate the unsatisfactory agreement to be expected on the average between the actual and graduated values of precipitation in individual years, using the regression coefficients of Table IV.

In view of the considerable local variation already known to prevail (2), it seemed unlikely that more satisfactory results would be obtained in individual years even in a smaller area, and this opinion was substantiated when the point was actually investigated. For this purpose, a series of 32 stations lying between north latitude 49½° and 52½°, and between west longitude 103½° and 108½° was selected. Table VIII lists the names of these, together with their latitude, longitude and altitude, and the total precipitation recorded at each during the months of April, July and October, 1935.

The linear regression coefficients b_1, b_2 and b_3 of the precipitation of these months on latitude, longitude and altitude were determined in the usual way, the Normal Equations of the Least Squares solution being:

$$\begin{array}{rrrcrrr} 73{,}456\,b_1 - & 4{,}568\,b_2 - & 343{,}419\,b_3 & = & 272.96; & -750.80; & 468.76 \\ -4{,}568\,b_1 + & 242{,}662\,b_2 + & 483{,}723\,b_3 & = & 374.14; & -8.76; & -125.17 \\ -343{,}419\,b_1 + & 483{,}723\,b_2 + & 3{,}790{,}454\,b_3 & = & 552.89; & 2602.02; & -1995.23 \end{array}$$

TABLE VIII

LATITUDE, LONGITUDE AND ALTITUDE OF METEOROLOGICAL STATIONS, AND TOTAL MONTHLY PRECIPITATION AS INCHES OF RAIN, 1935

Station	Lat. N. of 49°, min.	Long. W. of 103°, min.	Height above sea level, ft.	Total monthly precipitation, 1935		
				April	July	Oct.
Aneroid	42	258	2443	.75	2.69	.65
Anglia	154	310	1861	1.30	1.44	.86
Assiniboia	39	180	2450	.65	2.81	1.51
Beechy	110	266	2180	1.33	3.34	.64
Caron	88	173	1841	.95	1.35	.89
Chaplin	88	220	2202	.24	1.00	.70
Davidson	136	179	2030	.43	2.28	.88
Dundurn	168	210	1737	.53	2.89	1.54
Ft. Qu'Appelle	107	48	1600	.75	2.82	.55
Francis	67	50	1977	.50	4.26	.96
Gravelbourg	52	213	2297	.42	2.17	.75
Harris	164	273	1896	2.51	1.94	1.25
Humboldt	192	129	1865	.35	.62	1.09
Illerbrun	56	320	2925	.30	4.86	.90
Indian Head	88	40	1924	.65	3.12	.98
Lestock	137	57	2219	1.41	2.00	1.30
Lumsden	99	115	1620	.29	2.96	.29
Maskakee	199	161	1787	1.45	1.42	2.01
Moose Jaw	81	155	1860	.42	2.54	.84
Nokomis	150	120	1718	.57	.71	1.25
Outlook	148	245	1774	.43	2.58	1.04
Pennant	92	314	2346	1.91	1.63	.40
Qu'Appelle	91	56	2147	1.10	2.38	1.43
Regina	87	97	1884	.48	1.68	.87
Saskatoon	195	210	1600	1.89	2.78	2.56
Saskatoon Univ.	188	218	1690	1.65	2.50	2.36
Semans	146	106	1845	.81	1.48	.50
Shaunavon	37	322	3010	.66	2.55	.22
Strasbourg	125	117	1799	.40	1.38	.67
Swift Current	80	285	2440	1.53	3.40	.85
Tugaske	111	196	1986	.55	1.48	.40
Yellow Grass	49	69	1899	1.68	5.09	.97

These gave the values for the unknowns shown in Table IX.

TABLE IX

PARTIAL REGRESSION COEFFICIENTS OF MONTHLY PRECIPITATION (INCHES OF RAIN), 1935, ON LATITUDE (b_1), LONGITUDE (b_2) AND ALTITUDE (b_3) OF METEOROLOGICAL STATIONS

Month	b_1, 1/100's in. per 10′ N.	b_2, 1/100's in. per 10′ W.	b_3, 1/100's in. per 100 ft.
April	7.60 ± 2.88	0.03 ± 1.39	8.31 ± 4.64
July	-13.04 ± 5.29	0.95 ± 2.56	6.14 ± 8.52
October	7.68 ± 2.48	-0.95 ± 1.20	2.90 ± 4.00

The coefficients for latitude alone are of any statistical significance. The multiple correlation coefficients R between precipitation and latitude, longitude and altitude for the three months were found to be 0.48, 0.48 and 0.58

respectively, all very moderate values, and the residual standard deviation of precipitation to be 0.53, 0.97 and 0.46 inches respectively. Thus, the major part of the inter-station variance again remains in the form of residual deviations, and the conclusion with respect to this smaller district must be the same as that previously reached for the larger area, *viz.*, that a given number of meteorological stations would provide a much less complete quantitative specification of precipitation than of air temperature.

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THE FRESH-WATER MOLLUSCA OF SUB-ARCTIC CANADA[1]

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Abstract

A systematic account is given of the constitution, distribution and geographical affinities of the molluscan fauna occurring in fresh waters of sub-arctic Canada. The area covered is that part of western Ontario, Manitoba, Saskatchewan and Alberta lying north of N. Lat. 49°. A total of 111 species and varieties was collected and identified. Types of habitat available in this region for settlement by molluscs have been classified, and the local distribution of the species in them observed. A brief description of seven principal habitat types, with comments on their fauna in other parts of the sub-arctic region, is followed by a series of examples from specific localities. These molluscan associations, while not necessarily typical, are believed to be representative. The study is concluded with a comparison of the molluscan fauna of northern North America with that of northern Eurasia.

Three geographical elements in Canadian sub-arctic Mollusca are: a group of circumboreal species, a large number of strictly North American species, and a group characteristic of this region. An explanation of the close relation between the sub-arctic molluscs and those of the Mississippi drainage probably lies in the geological history of the region. There appears to have been a greater degree of speciation in North America than in northern Asia; the total number of species and varieties in sub-arctic Canada is 111, in northern Asia it is only 50. The explanation may lie partly in the richer source of supply, the greater facility for migration, and the wider range of habitats available in Canada. Thus new species as they arose would find suitable unoccupied habitats more readily. While this is hardly the sole explanation, the existence of some connection between physiography and speciation appears to be reasonable.

The following account deals with the constitution, distribution, and geographical affinities of the molluscan fauna of fresh waters in sub-arctic Canada. In so far as this report is based upon original observations in the field, it applies to the western part of the Province of Ontario, and to Manitoba, Saskatchewan and Alberta. Field work was carried on in that area from 1924 to 1931. During these and subsequent years the collections in several museums were studied, particularly those of the United States National Museum, and the British Museum (Natural History). This has made it possible to extend the scope of the work to include the whole of sub-arctic Canada. That is, it covers the greater part of the country lying to the north of N. Lat. 49°. Much of this vast territory remains to be explored, so that it is not possible to claim any degree of completeness in this work. Nevertheless sufficient is known about the mollusca of this region to justify an attempt to evaluate the fauna as a whole for purposes of comparison with other parts of the sub-arctic region.

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The first published account of the molluscs of this region, by G. M. Dawson, appeared in 1875. Other faunal lists, by Whiteaves (37, 38), Christy (11), and Hanham (16), followed. A general revision of the knowledge of the constitution of this fauna was undertaken by Dall during the early years of the present century, and was published in 1905. Since that time numerous short papers dealing with this fauna have appeared, and there has been a great advance in the study as a whole. A revision and extension of Dall's work is therefore needed.

Systematic Account

This part of the paper consists of a list of the species and varieties which have been examined by the author and found to be distinct from all other members of the fauna. Definite localities are given, and also in most instances a concise summary of the geographical range of the diverse forms. A great effort has been made to avoid errors in the identification of the species. During the early part of the work very valuable assistance was rendered by several North American malacologists in the determination of specimens. In this connection thanks are due particularly to Mr. F. C. Baker, and to Dr. Bryant Walker. The late Dr. Victor Sterki was kind enough to examine the Sphaeriidae. Whatever changes may be made in the nomenclature of the group in the future, each of the forms included in this list should be recognizable, as each name is known to represent an actual animal which exists in nature in some numbers.

OUTLINE OF THE CLASSIFICATION OF THE FRESH-WATER MOLLUSCA OF SUB-ARCTIC CANADA

—	Number of species and varieties	—	Number of species and varieties
GASTROPODA		PELECYPODA	
Family Lymnaeidae		Family Sphaeriidae	
Lymnaea	26	*Sphaerium*	12
Family Planorbidae		*Musculium*	5
Planorbis	17	*Pisidium*	15
Planorbula	3	Family Unionidae	
Family Physidae		*Quadrula*	1
Physa	4	*Amblema*	1
Aplexa	1	*Fusconaia*	1
Family Ancylidae		*Strophitus*	1
Ancylus	1	*Anodonta*	3
Ferrissia	2	*Anodontoides*	1
Family Viviparidae		*Lasmigona*	2
Campeloma	1	*Proptera*	1
Family Valvatidae		*Actinonaias*	1
Valvata	3	*Ligumia*	1
Family Amnicolidae		*Lampsilis*	3
Amnicola	5		
Total Gastropoda	63	Total Pelecypoda	48

Total fresh-water mollusca 111

In addition to the forms that have been collected and examined in the course of this investigation and are included in the list, there are a number of records of other species and varieties in the literature. In the absence of specimens it appears best to leave these out of consideration for the time being. There is little doubt however, that the records and descriptions of Canadian mollusca published within recent years by Mr. F. C. Baker are to be relied upon, so in instances in which the author has not had the opportunity of examining adequate series of these forms, the names are listed at the end of the respective families. This critical policy may have resulted in certain valid species and varieties being ignored in the present paper, but it has the advantage of providing a firm basis for the further study of this interesting group of animals.

Class GASTROPODA

Family Lymnaeidae

Genus *Lymnaea* s.s. Lamarck 1799

Lymnaea stagnalis jugularis Say

Lymnaea jugularis Say, Art. Conchology, Nicholson's Encyc. I. 1817.

Geographical Range. L. stagnalis is found in Europe, northern Africa, northern Asia, and North America. The variety *jugularis* is confined to North America, east and west of the Rocky Mountains, from California and New York to Alaska.

Northernmost record: Lake Harrison, N. Lat. 70°.

Southernmost record: N. Lat. 37° in Colorado, 41° in Illinois and Ohio.

Local Distribution in Canada. This is one of the commonest fresh-water molluscs in the western part of Canada, and is included in almost every list of species from this region. Only new records are included in the list given below. The previously reported localities are summarized by Dall (13), and others may be found in the more recent papers listed in the bibliography.

New records: Ontario—Oba River; Caramat; creek running into northern end of Long Lac; Nakina; Savant Lake district, Elbow Lake.

Manitoba—Lake Winnipegosis; marsh near the Meadow Portage; Grand Rapids of the Saskatchewan; Atikameg Lake, Mile 17, Hudson Bay Railway; Cormorant Lake, Mile 32, Hudson Bay Railway; Resting Lake, Mile 130; lake near Mile 137; creek at Mile 180.6; creek near Wintering Lake, Mile 186; lake near Mile 237; Split Lake; lake near Mile 286.

Alberta—Chestermere Lake, Calgary; Hastings Lake, Tofield; Hoople Lake, Entwistle; lake near Lac la Biche.

North West Territories—Mackenzie River delta.

Previous records published since Dall (13): Iglukitaktok, Mackenzie River delta, Dall (14). Southwest side of Mackenzie River, 30 miles above Fort Providence; at mouth of Hay River, Whittaker (39). Minaki, Ont., Winnipeg River, Mozley (21). Indian Bay station, Man.; Sturgeon Creek, near Winnipeg; St. Norbert, LaSalle River; Lockport; Clandeboye, Muckle Creek;

Grand Beach, the Grand Marais; Jackfish Creek near Jackfish Lake; Victoria Beach; Treesbank; Souris River; Baldur, slough near Cobbs Lake; Ninette, marsh at northern end of Pelican Lake, slough 5 miles north of Ninette; Douglas Lake near Onah; Theodore, Sask., Powells Lake; Ingebright, Mozley (23). Mud Turtle Lake, near Brereton, Man., Mozley (22). Whiteshell River district, Man., Little Whiteshell Lake, Crow Duck Lake, Whiteshell River above Jessica Lake; Molson; Beausejour; Portage la Prairie; Macdonald; Delta; Ninette, Bone Lake; Basswood, Long Lake; Clear Lake, Riding Mountains; Dauphin; Lake Winnipegosis, marsh near the Meadow Portage; Kuroki, Sask., Fishing Lake; Humboldt, Burton Lake; Yonker, Eyehill Creek, Mozley (24). Birtle, Man., marshes along the course of Birdtail Creek, also in many ponds and small lakes to the north of Birtle; Kamsack, Sask., pond one-half mile west of Kamsack, also in Madge Lake, 20 miles north of the town; Margo, Margo Lake; Kuroki, lake 1 mile west of Whitesand Lake; Wadena, Foam Lake; Paskwegin, pond near Paskwegin Brook, also in small lake 2 miles south of Paskwegin siding; Elfros, Brich Creek; Quill Lake station, Quill Creek; Watson, Ironspring Creek; small lakes between Kelliher, Touchwood, and Hudson Bay Lake; Dalesford, creek flowing into Lake Lenore 2 miles south of the hamlet of Dalesford, Mozley (25). Marchington River, Sioux Lookout district, Ont., Baker and Cahn (9). 2 miles west of Invermay, Sask.; north shore of Fishing Lake, near Wadena; 9 miles northeast of Goodeve; Sandy Creek waterworks, near Moose Jaw, Russell (36). Kennedy, Sask.; small lakes in the Moose Mountain Forest Reserve; Shonts, Alta., Amisk Creek; Tofield, Beaverhills Lake; Wabamun, Lake Wabamun, also in the marsh between Wabamun and Kapasiwin; Junkins, Chip Lake, Mozley (30). Fossil deposit on the shore of the Pasquaia River, near The Pas, Man., Mozley (31). Freshwater Lake, Charlton Island, James Bay, Richards (35).

Habitat. Ponds which contain water permanently, small lakes, marshes on the shores of larger bodies of water, also in small marshes along the borders of sluggish streams.

Lymnaea stagnalis jugularis occurs most abundantly in the prairie and parkland regions. It is not particularly common in the forested region, and has little toleration of saline conditions. It has not been collected in any temporary ponds.

Lymnaea stagnalis sanctaemariae Walker

Limnaea stagnalis sanctaemariae Walker, Nautilus, 6 : 31. 1892.

Geographical Range. North America, from the Great Lakes region northwest to Manitoba.

Northernmost record: Wekusko Lake, N. Lat. 54° 50′ (see below).

Southernmost record: Lake Michigan in N. Lat. 45°.

Local Distribution. New record: Wekusko (Herb) Lake, 10 miles west of Mile 81, Hudson Bay Railway, Man. Previous record: Lake Brereton, Man., Mozley (22).

Habitat. In large lakes, on smooth rocky shores sloping steeply into deep water in situations subject to severe wave action. In calm weather the

snails are to be found near the surface, but during storms they retire to the deeper water. The young individuals live in slightly more sheltered situations than the adults. The eggs of this variety, together with mature individuals, have been found in rock pools formed by the breaking of the waves on the shores, but this is probably not the usual site of egg-laying.

Lymnaea stagnalis lillianae Baker

Lymnaea stagnalis lillianae Baker.
Geographical Range. North America, from New York west to Manitoba.
Northernmost record: Shoal Lake, Manitoba, N. Lat. 49° 30′ (see below).
Southernmost record: Wisconsin, N. Lat. 46°.
Local Distribution. Previous records: Indian Bay, Shoal Lake, eastern Man., Mozley (24); Hill, Blackstone, St. Joseph, Bamaji, Fitchie, Abram, and Cat Lakes, Bamaji Lake outlet, Sioux Lookout district, Ont., Baker and Cahn (9).
Habitat. This variety has been found only on a sandy shore in Shoal Lake, where it was exposed to severe wave action.

Lymnaea stagnalis wasatchensis (Hemphill) Baker

Lymnaea stagnalis wasatchensis Baker, Chicago Acad. Sci., Spec. Pub. No. 3, 152. 1911.
Geographical Range. North America, confined to the western mountainous region.
Northernmost record: near Fort Anderson, N. Lat. 68°.
Southernmost record: Utah.
Local Distribution. Previous records: numerous localities in Jasper Park, N. Lat. 53°, Mozley (26, 30).
Habitat. The habitat of this variety in Jasper Park is usually among rooted aquatic plants in small lakes. It is occasionally found in larger bodies of water at relatively low altitudes (3000 to 4000 ft.).

Lymnaea (Pseudosuccinea) columella casta (Lea)

Lymnea casta Lea, Proc. Am. Phil. Soc. 2 : 33. 1841.
Geographical Range. North America, Ohio and Illinois north to Nova Scotia and Manitoba.
Northernmost record: Lake Brereton, Man. N. Lat. 49° 50′.
Southernmost record: *L. casta*, Ohio. *L. columella*, Florida, N. Lat. 27°.
Local Distribution. Previous record: Lake Brereton, eastern Man.
Habitat. In Lake Brereton this species was found on rocky shores in shallow bays where it was somewhat protected from wave action.
Remarks. Dall (13) records *L. columella* from Lake Winnipeg, and it may be that his record is based upon specimens of the variety *casta*.

Lymnaea (Bulimnea) megasoma (Say)

Lymnaeus megasoma Say, Rept. Longs Exped. 2 : 263. 1824.
Geographical Range. North America, from Vermont to Manitoba.
Northernmost record: Echimamish Lake district, Man., N. Lat. 57°.
Southernmost record: Stark Co., Ohio, N. Lat. 41°.

Local Distribution. New records: creek running into the northern end of Long Lac; Savant Lake district, Elbow and Heathcote Lakes, small lake south of Elbow Lake; Allenwater, Ont.

Previous records: Indian Bay station, Man., Falcon Bay, Mozley (21). Lake Brereton, Mozley (22). Whiteshell River district, shore of Whiteshell River below the unnamed lake 10 miles below Jessica Lake; quiet bay below third rapid below Betula Lake; near the eighth rapid below Betula Lake, Mozley (24). Rennie, Rennie River, Mozley (25). Marchington River; Bamaji Lake; Cat and Hill Lakes, Baker and Cahn (9).

Habitat. Lakes, ponds, and streams. Commonly but not invariably found in situations which are free from wave action. On shores and lake bottoms composed of rock, sand, and mud, and also among aquatic plants and in marshes. In favorable situations it may occur in large numbers.

Lymnaea (Stagnicola) caperata (Say)

Lymnaeus caperatus Say, New Harmony Diss. 2 : 230. 1829.

Geographical Range. North America, from Maryland, Colorado and California north to the mouth of the Mackenzie River.

Northernmost record: 30 miles north of Aklavik, N. Lat. 68° (approx.).

Southernmost record: Colorado.

Local Distribution: New records: Calgary, Alta.; 30 miles north of Aklavik, N.W.T.

Previous records: Molson, Man.; Navin; Sifton; Lake Winnipegosis, marsh near the Meadow Portage, Mozley (24). Fort Frances, Ont.; Grande Pointe, Man.; Birtle; Kamsack, Sask.; Elfros, Brich Creek; Kuroki, Van Patten Creek; Clair, Clair Brook; Quill Lake station, Quill Creek; Watson, Ironspring Creek; Lanigan; Kelliher; Touchwood; Dalesford, creeks flowing into Lake Lenore, Mozley (25). Wainwright, Alta., Viking; Kinsella; Irma; Shonts; Tofield; ponds near Cooking Lake; Lindbrook; Edmonton; Junkins, Chip Lake; Peace River district, 1 mile east of Faust; also along the shores of Lesser Slave Lake near Faust; Wanham, pond in the Birch Hills; creek entering Cadotte Lake from the south; 3 miles north of Spirit River, Mozley (30).

Habitat. Usually in temporary ponds, but sometimes to be found in marshes. This is a very common species on the prairies and parkland. It is somewhat less abundant in the forested region.

Lymnaea (Fossaria) umbilicata (C. B. Adams)

Limnaea umbilicata C. B. Adams, Am. J. Sci. 39 : 374. 1840.

Geographical Range. North America, New Jersey and Maine west to Manitoba.

Northernmost record: Birtle, Man., N. Lat. 50° 25′.

Southernmost record: Burlington, New Jersey.

Local Distribution. The only known occurrence of this species in the western part of Canada is at Birtle.

Habitat. The specimens were collected in a small marsh along the edge of Birdtail Creek.

Remarks. Mr. F. C. Baker identified the shells upon which this record is based.

Lymnaea (Fossaria) parva sterkii Baker

Lymnaea sterkii Baker, Nautilus, 19 : 51. 1905.
Geographical Range. North America, New York to Minnesota, Manitoba, and Alberta. *L. parva* f.t.—"James Bay . . . . . . Maryland . . . . . . Arizona", Baker (1).
Northernmost record: Jasper Park, Alta., N. Lat. 53°.
Southernmost record: Hickman Co., Tennessee.
Local Distribution. Previous records: Birtle, Man.; Jacques Lake district, tributaries of the Rocky River, Jasper Park, Alta.
Habitat. In both the above localities this snail was found in marshy areas along the border of streams. It appears to prefer muddy flats on which there is little vegetation.

Lymnaea (Fossaria) dalli Baker

Lymnaea dalli Baker, Bull. Ill. State Lab. Nat. Hist. 7 : 104. 1906.
Geographical Range. North America, from Kansas and Arizona through Ohio and Montana to Manitoba and Alberta.
Northernmost record: Pyramid Lake, Jasper Park, Alta., N. Lat. 53°.
Southernmost record: southern Arizona, N. Lat. 32° (approx.).
Local Distribution. Manitoba, Saskatchewan, and Alberta.
Habitat. Marshes and small lakes, usually among vegetation. This species has not been found in ponds, and appears to have little ability to withstand saline conditions.

Lymnaea (Fossaria) modicella (Say)

Lymnaeus modicellus Say, J. Phil. Acad. 5 : 122. 1825.
Geographical Range. North America, Texas to Nova Scotia and California, north to Manitoba.
Northernmost record: Ninette, Man., N. Lat. 49° 25′.
Southernmost record: Texas.
Local Distribution. Previous record: near Round Lake, Ninette.
Habitat. The habitat in the above locality is a small mud flat.

Lymnaea (Fossaria) obrussa decampi (Streng)

Limnaea desidiosa var. *decampi* Streng, Nautilus, 9 : 123. 1906.
Geographical Range. North America, Maine to Illinois, Manitoba, and Alberta.
Northernmost record: near Fort Providence, Mackenzie River, N. Lat. 61°.
Southernmost record: Illinois.
Local Distribution. New record: lake near Mile 137, Hudson Bay Railway. Previous records: Southwest side of Mackenzie River, 30 miles above Fort Providence, Mackenzie River district (as above); Mills Lake at mouth of Horn River, Whittaker (39). Clearwater (Atikameg) Lake, Mile 17, Hudson Bay Railway, Mozley (24). Bamaji, Hamilton, Cat, Pashkokogan Lakes, and

outlet of Kapikik Lake, Ont., Baker and Cahn (9). Postglacial fossil deposit near Lavenham, Man., Mozley (31).

Habitat. Lakes of moderate or large size, usually those which have clear and cold waters.

Lymnaea (Fossaria) exigua (Lea)

Lymnea exigua Lea, Proc. Am. Phil. Soc. 2 : 33. 1841.

Geographical Range. North America, Tennessee north to Maine and Manitoba.

Northernmost record: creek running into the Grand Marais, at a point two miles east of Balsam Bay, Man., N. Lat. 50° 20′.

Southernmost record: Tennessee.

Local Distribution. Previous records: Mile 69, G.W.W.D.Ry., Man., Mozley (21). Onion Lake, near Minaki, Ont.; Clandeboye, Man., Mozley (24). Bamaji Lake outlet, Sioux Lookout district, Ont., Baker and Cahn (9).

Habitat. Usually in small marshy streams, or on the protected shores of small lakes.

Lymnaea (Stagnicola) palustris (Müller)

Buccinum palustre Müller, Verm. Terr. 2 : 131. 1774.

Geographical Range. Europe, northern Africa, northern Asia, North America. In North America from New Jersey, Arizona and California, north to James Bay, and Alaska.

Northernmost record: lake at N. Lat. 68° 20′, W. Long. 141°.

Southernmost record: Arizona.

Local Distribution. New records: Fishing River station; Barrows Junction; Clear Lake, Riding Mountain; Miles 82 and 130, Hudson Bay Railway; small creek near Wintering Lake, Mile 186; ponds on the tundra north of Mile 510; tundra ponds near Esquimo Point, Man. Moose Jaw Creek, Sask. Deep Creek, 12 miles south of Entwistle; near Lac la Biche, Alta.

Previous records: Bernard Harbour, Arctic Coast, in part (?) described by Baker (6) as *Stagnicola kennicotti*, Dall (14); southwest side of Mackenzie River, 30 miles above Fort Providence, Mackenzie River district; south shore Second Lake, Horn River; Mills Lake at mouth of Horn River; at mouth of Hay River; south shore Great Slave Lake, near Sulphur Point, Whittaker (39). Mile 69, G.W.W.D.Ry., Man., Mozley (21). Indian Bay station, eastern Man.; Winnipeg, Catfish Creek; St. Vital; St. Norbert, La Salle River; Clandeboye, Muckle Creek; Goldeye Lake, near mouth of the Red River; Matlock; Balsam Bay, small pond in creek running into the Grand Marais, 2 miles east of Balsam Bay station; Jackfish Lake and Creek; Steep Rock; Aweme, slough near tamarack swamp; Ninette, marshy shores of Pelican Lake; Theodore, Sask., Whitesand River; Edmonton, Alta., Mozley (23). Cartier, Man., Stony Mountain; Portage la Prairie; Macdonald; Dauphin; Sifton; Molson; Delta, Mozley (24). Grande Pointe, Man., Kamsack, Sask.; Madge Lake, Duck Mountain; Kuroki; Paskwegin, Paskwegin Brook, also in Little Quill Lake; Clair, Clair Brook; Quill Creek; Wynyard; Watson, Ironspring Creek; Kelliher; Touchwood; Dalesford, Mozley (25).

Jasper Park, Alta., pond between Patricia and Katrine Lakes; Lake Mildred, Mozley (26). Wadena, Sask., north shore of Fishing Lake; Moose Jaw, Sandy Creek waterworks, Russell (36). Langbank, Sask.; Kennedy; small lakes in Moose Mountain Forest Reserve; Regina, Pile of Bones Creek; Bethune, near mouth of the Arm River; Wainwright, Alta.; Viking; Phillips; Kinsella; Irma; Shonts; Tofield, Beaverhills Lake, also in Amisk Creek; 3 miles southwest of Tofield; ponds near Cooking Lake; marsh between Wabamun and Kapasiwin; Junkins, Chip Lake; Peace River district, McLennan, Kimiwan Lake, Kinuso, Strawberry Creek near Lesser Slave Lake; Wanham, pond in the Birch Hills 4 miles south of Wanham, also in Cadotte (Ka Kut) Lake; 3 miles north of Spirit River; near White Mountain, Spirit River, Mozley (30). Agassiz clay near Fort Frances, Ont.; postglacial fossil deposit on the shore of the Pasquaia River near The Pas, Man., Mozley (31). Abitibi River, 12 miles north of Iroquois Falls, Ont., Richards (35).

This species has a very wide range in the western part of Canada, but is more common on the prairie and parkland than elsewhere.

Habitat. Temporary and permanent ponds, small and large lakes, streams. *L. palustris* thrives in temporary ponds in which there is water for only two months in each year. It occurs in large numbers in permanent ponds, small lakes, marshes, and usually in the more sluggish streams. It has also been found on a sandy shore of Lake Winnipeg in a position only slightly protected from wave action. It has a marked resistance to saline conditions, occurring in considerable numbers in parts of the Little Quill Lake, Sask. The waters of this lake were found to contain about 9700 parts per million of dissolved materials, chiefly sodium chloride, sodium sulphate, and magnesium sulphate (see Mozley, 25).

Remarks. Lymnaea palustris is an exceedingly variable species, and in the past different names have been applied to the variant forms. Since the range of variation is so great (see Mozley, 32), it appears best to adopt a single general name for the majority of the animals of this group. Subspecific names may be recognized later. Since large series of the species and varieties recently described by Baker (5–7) have not been available, it has been impossible to study them critically, and they are not included in this account. This does not necessarily mean that they are unrecognizable as distinct races, but merely that the writer has been unable to reach any conclusion regarding them.

Lymnaea (Stagnicola) palustris castorensis Mozley

Lymnaea traskii castorensis Mozley, Proc. Malac. Soc. London, 20 : 241. 1933.

Geographical Range. North America, a pond formed by beavers *(Castor canadensis)* near Medicine Lake, Maligne drainage, Jasper Park, Alta. This is the only known locality.

Remarks. In the original description this form was given as a variety of *L. traskii* Tryon. As that "species" appears to be merely a variant of the *palustris* group it may be preferable to treat *castorensis* as a variety of *palustris.*

Lymnaea (Stagnicola) traskii (Tryon)

Limnaea traskii Tryon, Proc. Phil. Acad. 149. 1863.
Geographical Range. North America, confined to the western mountainous region.
Northernmost record: Twin Lakes, Maligne drainage, Jasper Park, Alta.
Southernmost record: California.
Local Distribution. Banff, and numerous localities in Jasper Park. (Mozley, 26).
Habitat. This species is usually found on open shores of large lakes but has also been collected in ponds.

Lymnaea (Stagnicola) saskatchewanensis Mozley

Lymnaea vahlii saskatchewanensis Mozley, Am. Mid. Nat. 13 : 236. 1932.
Geographical Range. North America, interglacial deposit near Beaubier, Sask.
Remarks. Mr. F. C. Baker considers that this should be regarded as a distinct species.

Lymnaea (Stagnicola) hedleyi Baker

Lymnaea hedleyi Baker, Nautilus, 40 : 23. 1927.
Geographical Range. North America, the headwaters of the Fraser River, British Columbia.
Local Distribution. New record: Lucerne, B.C., Fraser River.
Previous record: Red Pass Junction, Fraser River (Baker, *loc. cit.*).
Habitat. This species was found in large numbers on stones on the bottom of the Fraser River in places where the current was strong, but the surface of the water unbroken.
Remarks. The new record extends the known distribution of this species upstream to within a few miles of the continental divide at the Yellowhead Pass.

Lymnaea (Stagnicola) lanceata (Gould)

Limnaea lanceata Gould, Proc. Boston Soc. Nat. Hist. 3 : 64. 1848.
Geographical Range. North America, Ohio and Wisconsin north to Ontario and Manitoba.
Northernmost record: Canyon Lake, Ont., N. Lat. 50° (approx.).
Southernmost record: Summit Co., Ohio, N. Lat. 41°.
Local Distribution. New record: Canyon Lake.
Previous records: Mile 95, G.W.W.D.Ry., Mozley (23); several localities on the Whiteshell River, Mozley (24); Lake Brereton, Man., Mozley (22).
Habitat. Marshes, particularly those near streams or large bodies of water.

Lymnaea (Stagnicola) catascopium Say

Lymnaea catascopium Say, Nich. Encyc., Amer. Ed. 2. 1817.
Geographical Range. North America, Maryland, Ohio, and Nova Scotia.
Northernmost record: Great Slave Lake, N. Lat. 61°.
Southernmost record: Maryland.

Local Distribution. Previous records: Lake Winnipeg, Mozley (23).
Habitat. Exposed shores of large lakes, particularly those which are strewn with large boulders.

Lymnaea (Stagnicola) emarginata (Say)

Lymnaeus emarginatus Say, J. Phil. Acad. 2 : 170. 1821.
Geographical Range. North America, from New York, Michigan and Ontario to Alberta.
Northernmost record: Grand Rapids of the Athabasca, N. Lat. 56° (approx.).
Southernmost record: New York State, N. Lat. 45°.
Local Distribution. New record: Grand Rapids of the Athabasca.
Previous records: Lake Winnipeg, Mozley (23); Lake Winnipegosis; Atikameg Lake, Mile 17, Hudson Bay Railway, Mozley (24).
Habitat. The shores of large lakes, particularly those which are subject to severe wave action.

Lymnaea (Stagnicola) emarginata angulata (Sowerby)

Limnaea angulata Sowerby, Conch. Icon. 18 : Lim. No. 47. 1872.
Geographical Range. North America, Michigan to Manitoba.
Northernmost record: Winnipeg River, Man., N. Lat. 50° 15′.
Southernmost record: Michigan.
Local Distribution: Previous record: Winnipeg River, near the mouth of the Whitemouth River, Mozley (21).

Lymnaea (Stagnicola) emarginata canadensis (Sowerby)

Limnaea canadensis Sowerby, Conch. Icon. 18 : Lim., sp. 45. 1872.
Geographical Range. North America, from New York north to Anticosti, and west through Michigan and Wisconsin to Manitoba and Alberta.
Northernmost record: Northern Twin Lake, Maligne drainage, Jasper Park, Alta., N. Lat. 53°.
Southernmost record: southern New York, Baker.
Local Distribution. Winnipeg River, near Minaki, Ont., Mozley (21); numerous localities in Jasper Park, Mozley (26).

Lymnaea (Stagnicola) walkeriana (Baker)

Stagnicola walkeriana Baker, Nautilus, 39 : 119. 1926.
Geographical Range. North America, Lakes Superior and Michigan, far western Ontario.
Northernmost record: Winnipeg River, N. Lat. 50°.
Southernmost record: Lake Michigan, near Sturgeon Bay.
Local Distribution. Previous records: English River, near its junction with the Winnipeg River; Lost Lake, near Minaki, Ont.

Lymnaea preblei Dall

Lymnaea preblei Dall, Harriman Alaska Exped. 13 : 70. 1905.
Geographical Range. North America, far western Ontario, northern Manitoba and Saskatchewan.

Northernmost record: Clear Lake, Sask., N. Lat. 56°.
Southernmost record: English River, Ont.
Local Distribution. Previous records: English River; Knee Lake, northern Man.; Lac Ile à la Crosse, and Clear Lake.
Remarks. This is a recognizable form which will probably prove to be closely related to *L. emarginata*. *L. binneyi* is omitted from this account as it appears difficult to recognize the limits of its variation, some of the named specimens approaching *L. emarginata* very closely.

Lymnaea randolphi Baker

Lymnaea randolphi Baker, Nautilus, 18 : 63. 1904.
Geographical Range. North America, Yukon Territory and Alaska.
Northernmost record: lake near Cosmos River, north of the Kowak River, Alaska, about N. Lat. 68°.
Southernmost record: Lake Lindeman, Y.T., N. Lat. 60°.
Local Distribution. Several localities in the Yukon Territory and Alaska.
Remarks. Dall (13, p. 71) and Baker (1, p. 453) cite a locality in the Lillooet district of British Columbia. The specimens in the United States National Museum from this locality are altogether distinct from *L. randolphi*. The locality from Washington given by Dall is also erroneous.

Lymnaea atkaensis (Dall)

Lymnaea ovata var *atkaensis* Dall, Proc. U.S. Nat. Mus. 7 : 343. 1884.
Geographical Range. Aleutian Islands, Behring Sea.
Local Distribution. Lake on the Island of Atka, Aleutian Chain, near Korovin Bay (Dall).

Lymnaeidae Reported on Good Authority to Occur in Sub-arctic Canada, but not Examined by the Author

Lymnaea (Stagnicola) alberta (Baker), Brazeau Lake, Alta., Baker (2). This species has not been recognized among the collections from Brazeau Lake made by the present author. Most of the specimens from this lake, and the valley below it as far north as Isaac Creek, were *L. traskii* or similar members of the palustris group.
Lymnaea (Stagnicola) exilis Lea, reported from several localities in the Sioux Lookout district by Baker and Cahn (9). None have been seen by the author. Specimens of *L. lanceata* (Gould) from Canadian localities have been compared and found to be identical with the type in the collection of the United States National Museum.
Lymnaea (Stagnicola) catascopium kempi (Baker and Cahn (9)), reported from several localities in the Sioux Lookout district, Ont.
Lymnaea (Stagnicola) palustris alpenensis Baker, reported from Bamaji Lake, Sioux Lookout district, by Baker and Cahn (9).
Lymnaea (Stagnicola) kennicotti (Baker) (6), Bernard Harbour, Arctic Canada.
Lymnaea (Stagnicola) palustris ungava (Baker) (6), Fort Chimo, Ungava.

Family Planorbidae

Genus *Planorbis* Geoffroy 1767

Planorbis (Helisoma) antrosus Conrad

Planorbis antrosus Conrad, Am. J. Sci. 25 : 343. 1834.
Geographical Range. North America, from Alabama and Arkansas north to Massachusetts, Illinois and Manitoba.
Northernmost record: Birtle, Man., N. Lat. 50° 20′.
Southernmost record: Alabama.
Local Distribution. Previous record: Birtle, Mozley (23).
Habitat. These specimens were collected in Birdtail Creek, near Birtle.
Remarks. These shells were *P. antrosus* f.t., but some individuals approached the variety *portagensis* Baker.

Planorbis (Helisoma) antrosus sayi (Baker)

Helisoma antrosa sayi Baker, Bull. Wisc. Geol. & Nat. Hist. Surv. 70 : 322. 1928.
Geographical Range. North America, New York, the Great Lakes region, Ontario to Alberta.
Northernmost record: Knee Lake, northern Man., N. Lat. 55°.
Southernmost record: ? New York.
Local Distribution. New records: Knee Lake.
Previous records: Indian Bay station, Man., Falcon Bay; Mozley (23). Lake Brereton; Mud Turtle Lake, Mozley (22). Lake Winnipegosis; Mossy River near Winnipegosis, Mozley (24). Madge Lake, north of Kamsack, Sask., Mozley (25). Pyramid Lake, Jasper Park, Alta., Mozley (26). Wabamun, Alta., Lake Wabamun, Mozley (30). Postglacial fossil deposit, near Lavenham, Man., Mozley (31).
Habitat. Usually in small streams or those of moderate size.

Planorbis (Helisoma) antrosus royalensis Walker

Planorbis bicarinatus royalensis Walker, Nautilus, 23 : 9. 1909.
Geographical Range. North America, Isle Royale, Lake Superior; far western Ontario.
Northernmost record: Lac Seul district, Ont., N. Lat. 50° (approx.).
Southernmost record: Isle Royale, N. Lat. 48°.
Local Distribution. Previous records: Bamaji, St. Joseph, Hamilton, Cat and Botsford Lakes; outlet of Bamaji Lake, Ont., Baker and Cahn (9).

Planorbis (Helisoma) trivolvis Say

Planorbis trivolvis Say, Nich. Encyc., 1st ed., II, pl. ii, fig. 2. 1817.
Geographical Range. North America, far northeastern Asia. In North America, from Tennessee and Missouri north to Alaska.
Northernmost record: Fort Yukon, Alaska, N. Lat. 66° 40′.
Southernmost record: Tennessee.

Local Distribution. *P. trivolvis* has been reported from a great many localities in sub-arctic Canada. It is most abundant on the prairies, and least common in the forested region. There are shells in the collection of the United States National Museum from the Seward Peninsula, Alaska, labelled, "Under 12 ft. muck on cobbles." Baker (8) is of the opinion that many of the previous records of *P. trivolvis* actually relate to other species, but reports that the typical form is found as far north and west as Wainwright, Alta.

Habitat. *P. trivolvis* is usually found in marshy places along the borders of lakes or along the edges of streams. It has little ability to withstand saline conditions, but appears to be able to withstand desiccation to a very slightly greater extent than *Lymnaea stagnalis*.

Planorbis (Helisoma) trivolvis pilsbryi Baker

Planorbis trivolvis pilsbryi Baker, Nautilus, 39 : 117. 1926.

Geographical Range. North America, Massachusetts and New York west to Wisconsin, Ontario, and Manitoba.

Northernmost record: Landing River, northern Man., N. Lat. 56°.

Southernmost record: northern New York.

Local Distribution. New record: Landing River, second portage from the Hudson Bay Railway on the route to Split Lake.

Previous records: Indian Bay station, Man., Falcon Bay; Brereton, Lake Brereton, Mozley (25). Marchington River, Sioux Lookout district; Sturgeon Lake, Rainy River district, Baker and Cahn (9).

Habitat. In marshes, and on submerged vegetation in situations protected from wave action.

Planorbis (Helisoma) corpulentus Say

Planorbis corpulentus Say, Longs Exped. 2 : 262. 1824.

Geographical Range. North America, northern Michigan and Minnesota, Ontario, Manitoba, and Saskatchewan. This species is confined to the forested region.

Northernmost record: Lac Ile à la Crosse, Sask., N. Lat. 55° 45′.

Southernmost record: northern Minnesota, Baker.

Local Distribution. Numerous localities in far western Ontario, Mozley (21), Baker and Cahn (9). Also known to occur at Falcon Bay, Shoal Lake, eastern Man., Mozley (24).

Habitat. Lakes and streams. Usually in somewhat protected situations, but not in marshes.

Planorbis (Helisoma) corpulentus multicostatus (Baker)

Helisoma corpulentum multicostatum Baker, Nautilus, 46 : 7. 1932.

Geographical Range. North America, far western Ontario.

Local Distribution. Kahnipiminanikok Lake, Rainy Lake district; Cherry Island, Rainy Lake; Root River (McInnes coll.); Hill, Birch and St. Joseph Lakes, Kenora district; swamp of Lac des Mille Lacs, Sturgeon and Abram Lakes, Thunder Bay district, all in Ontario, Baker (8).

Planorbis (Helisoma) infracarinatum (Baker)

Helisoma infracarinatum Baker, Nautilus, 46 : 8. 1932.
Geographical Range. North America, Ontario, Manitoba, northern United States.
Northernmost record: Wekusko Lake, N. Lat. 54° 50′.
Southernmost record: "The United States," Baker.
Local Distribution. New records: Isle La Crosse, English River *(sic)*, U.S.N.M. No. 29231, Kennicott coll., det. Baker; Wekusko (Herb) Lake, 10 miles west of Mile 81, Hudson Bay Railway.
Previous record: Basswood River rapids, Rainy River district, Ont., Baker (8).

Planorbis (Helisoma) campanulatus wisconsinensis Winslow

Planorbis campanulatus wisconsinensis Winslow, Occ. Papers Mus. Zool. Univ. Mich. 180 : 5. 1926.
Geographical Range. North America, Michigan and Quebec, west to Illinois, Ontario, and Manitoba. This variety is confined to the forested region.
Northernmost record: Landing Lake, Hudson Bay Railway, N. Lat. 55° 20′.
Southernmost record: Michigan.
Local Distribution. New record: Landing Lake.
Previous records: Indian Bay station, Man., Falcon Bay; Minaki, Ont., Winnipeg River; Star Lake near Redditt; Alice and Onion Lakes near Minaki; English River near its junction with the Winnipeg River, Mozley (21). Snake Lake, near Indian Bay station, Man., Mozley (23). Brereton and Mud Turtle Lakes, Mozley (22). Several small lakes on Duck Mountain near Madge Lake, north of Kamsack, Sask., Mozley (25).
Habitat. Small lakes, and also to some extent in those of moderate size. Frequently found on bare stones and rock faces, but not in the most exposed situations.

Planorbis (Helisoma) campanulatus rudentis Dall

Planorbis campanulatus var. *rudentis*, Dall, Harriman Alaska Exped. 13 : 90. 1905.
Geographical Range. North America, Michigan to Manitoba.
Northernmost record: Knee Lake, Man., N. Lat. 55°.
Southernmost record: Marl Lake, Roscommon Co., Michigan.
Local Distribution. Knee Lake.

Planorbis (Helisoma) campanulatus davisi Winslow

Planorbis campanulatus davisi Winslow, Occ. Papers Mus. Zool. Univ. Mich. 180 : 8. 1926.
Geographical Range. North America, Michigan to southern Manitoba.
Northernmost record: Douglas Lake, near Onah, Man., N. Lat. 49° 45′.
Southernmost record: Pinnebog River, Huron Co., Michigan.
Local Distribution. Previous record: Douglas Lake, Mozley (24).

Planorbis (Menetus) exacuous Say

Planorbis exacuous Say, J. Phil. Acad. 2 : 168. 1821.

Geographical Range. North America, east of the Rocky Mountains, from New Mexico north to Alaska.

Northernmost record: left bank of the Yukon River below Fort Yukon (Pleistocene marl), N. Lat. 66° 40′.

Southernmost record: New Mexico.

Local Distribution. Previous records: south shore Second Lake, Horn River; south shore Lake Kakisa, near mouth of Kakisa River, Mackenzie River district, Whittaker (39). Minaki, Ont., Winnipeg River, Mozley (21). Indian Bay station, Man., Falcon Bay, and Snake Lake; Grand Beach; Douglas Lake near Carberry, Mozley (23). Lake Brereton, Mozley (22). Whiteshell River district, Whiteshell Lake and vicinity; small lake on portage between Whiteshell and Crow Duck Lakes; Macdonald; Lake Winnipegosis, near the Meadow Portage, and on the lake bottom near Snake Island; Clearwater (Atikameg) Lake, Hudson Bay Railway, Mozley (24). Small lake one-half mile west of Madge Lake, north of Kamsack, Sask.; Wadena, Foam Lake; Kuroki, Van Patten Creek; Kelliher; Touchwood, Mozley (25). Hibernia Lake near Jasper, Alta., also in Marjorie, the larger Trefoil Lake, an unnamed lake north of Geikie station, Annette, Caledonia, Edna, and Pyramid Lakes, pond in the bed of Pyramid Creek, and other localities, Mozley (26). Small lakes in Moose Mountain Forest Reserve, Sask.; Phillips, Alta.; Tofield, Beaverhills Lake; Junkins, Chip Lake; Peace River district, creek 3 miles east of Driftpile; Wanham, Cadotte Lake, Mozley (30). Cat, Bamaji and Kimmewin Lakes, Sioux Lookout district, Ont., Baker and Cahn (9).

Habitat. Temporary ponds, small lakes, marshes, on the bottom of large lakes, *e.g.*, Lake Winnipegosis.

Planorbis (Menetus) exacuous megas Dall

Planorbis exacuous var. *megas* Dall, Harriman Alaska Exped. 13 : 91. 1905.

Geographical Range. North America, described from Birtle, Man. Stated by Baker (3) to be a northern form found principally in Wisconsin, Michigan, and Minnesota.

Local Distribution. Cat, Bamaji, and Kimmewin Lakes, Ont., Baker and Cahn (9).

Planorbis (Gyraulus) deflectus Say

Planorbis deflectus Say, Rept. Longs Exped. 2 : 261. 1824.

Geographical Range. North America, Massachusetts west to Nebraska, and north to Manitoba.

Northernmost record: Victoria Beach, Man., N. Lat. 50° 40′.

Southernmost record: Nebraska.

Local Distribution. Previous records: Victoria Beach; Jackfish Lake, east of Balsam Bay, Man., Mozley; Clearwater Lake, Hudson Bay Railway, Mozley (24).

Remarks. Dall (13) records *P. deflectum* from Great Slave Lake and Alaska. The specimens upon which these records are based are in the U.S. National Museum and are not *deflectus.* Some shells of this species approach *P. acronicus* Férussac.

Planorbis (Gyraulus) arcticus "Beck" Möller

Planorbis arcticus (Beck Mss.) Möller, Index Moll. Groenl. p. 5. 1842.
Geographical Range. North America and Greenland.
Northernmost record: Greenland or Alaska.
Southernmost record: Illinois (fossil), Baker.
Local Distribution. Previous records: Mackenzie River district, south shore of Fawn and Second Lakes, Horn River; western end Lake Kakisa; south shore Lake Kakisa near mouth of the Kakisa River; south side of Mills Lake, Whittaker (39). Sioux Lookout district, Ont., Kimmewin, Bamaji, Cat, St. Joseph, Hamilton, Kapikik, Pashkokogan, and Fitchie Lakes, Baker and Cahn (9).
This is a common species in the territory extending from Ontario to the Mackenzie basin. In the past it has been mistaken for *P. parvus* Say.

Planorbis (Gyraulus) umbilicatellus Cockerell

Planorbis umbilicatellus Cockerell, Conch. Exchange, 2 : 68. 1887.
Geographical Range. North America, New Mexico north to Manitoba.
Northernmost record: Touchwood, Sask., N. Lat. 51° 30′.
Southernmost record: Mesilla, New Mexico, N. Lat. 32° 15′.
Local Distribution. Previous records: St. Vital, Man., Mozley (21). Brereton, Mozley (22). Grande Pointe; Birtle; Kelliher, Sask.; Touchwood, Mozley (25). Small lakes and ponds in Moose Mountain Forest Reserve; Wainwright, Alta.; Viking; Shonts; Tofield; ponds near Cooking Lake; Edmonton; Peace River district, 3 miles north of Spirit River, Mozley (30).
Habitat. P. umbilicatellus occurs only in temporary ponds. The explanation of the rarity of this species in the forested region lies in the fact that the small basins which form its sole habitat are quickly filled with vegetation in that region.

Planorbis (Gyraulus) crista (Linné)

Nautilus crista Linné, Syst. Nat., ed. 10 : 709. 1758.
Geographical Range. Europe, northern Africa, northern Asia, North America.
Northernmost record: Fort Yukon, Alaska, N. Lat. 66° 40′.
Southernmost record: Illinois, Baker.
Local Distribution. New records: Fort Yukon; Athabasca Delta, Alta.
Previous records: Virl Lake, near Jasper, Alta.; also in the smaller Trefoil Lake, and Lake No. 6, Mozley (26). Tofield, Alta., Mozley (30).
Habitat. Ponds and small lakes.

Genus *Planorbula* Haldeman 1842

Planorbula armigera Say

Planorbis armigerus Say, J. Phil. Acad. 2 : 164. 1818.
Geographical Range. North America, Louisiana and Georgia, north to New England and Canada.
Northernmost record: ? Manitoba, see below.
Southernmost record: Louisiana.
Local Distribution. Previous records: at mouth of Hay River, Mackenzie River district, Whittaker (39). Grand Beach, Man., the Grand Marais; Ninette, northern end of Pelican Lake, Mozley (23). Sioux Lookout district, Ont., Bamaji, Cat, St. Joseph, Botsford, Hamilton, and Fitchie Lakes, Baker and Cahn (9).
Remarks. With the exception of the records mentioned above the reports of this species from Canada must be regarded as doubtful as they may refer to the more recently described *P. crassilabris.*

Planorbula crassilabris Walker

Segmentina crassilabris Walker, Nautilus, 20 : 122. 1907.
Geographical Range. North America, Michigan, Iowa, north to Canada.
Northernmost record: Balsam Bay, Man., N. Lat. 50° 30′.
Local Distribution. Previous records: Waugh (Indian Bay station) near mouth of the Falcon River, Man., Mozley (20). Arnaud; Balsam Bay, small pond in creek flowing into the Grand Marais, 2 miles east of Balsam Bay station, Mozley (23). Lake Brereton, Mozley (22). Grande Pointe, Mozley (25). Junkins, Alta., Chip Lake; marsh between Kapasiwin and Wabamun; Peace River district, Kinuso, Strawberry Creek near Lesser Slave Lake; pond near Mile 196.7, E.D. & B.C. Ry.; small creek near Faust, Mozley (30).
Habitat. Ponds, small lakes, and marshes.

Planorbula campestris Dawson

Geographical Range. North America, from South Dakota to the North West Territories.
Northernmost record: Mackenzie River, 30 miles above Fort Providence, N.W.T., N. Lat. 61°, Whittaker (39).
Southernmost record: Coteau Hills, 5 miles northeast of Clear Lake, South Dakota.
Local Distribution. Previous records: Mackenzie River district, south shore Fawn Lake, Horn River; southwest side of Mackenzie River, 30 miles above Fort Providence; Mills Lake at mouth of Horn River; south side Mills Lake, Whittaker (39). Beulah, Man., Wade's slough, Mozley (23). Wadena, Sask., Mozley (24). Birtle, Man., Kelliher, Sask.; Touchwood, near Hudson Bay Lake, Mozley (26). Ponds in Moose Mountain Forest Reserve; Phillips, Alta.; Viking; Tofield; Peace River district, 3 miles north of Spirit River.
This species has not yet been found in the densely forested region by the author. The precise habitat is not known of the specimens upon which the

records from the Mackenzie River district are based, but in that region this species may be confined to "islands" of grassland in the forest.

Habitat. Temporary ponds, rarely in permanent ponds which have a temporarily flooded area surrounding them.

Planorbidae Reported on Good Authority to Occur in Sub-arctic Canada, but not Examined by the Author

Planorbis (Helisoma) whiteavesi (Baker (5)), Lac des Mille Lacs, Thunder Bay district, Ont.

Planorbis (Helisoma) plexata Ingersoll (Baker (8)), Harricanaw River; Black Bear Island, Lake Winnipeg; Cormorant Lake, Man.; Athelstane Lake, Ont.

Planorbis (Helisoma) hornii Tryon (Baker (8)), Fort Simpson, Mackenzie River.

Planorbis (Helisoma) subcrenatus Carpenter (Baker (8)), New Osgoode, Sask.; Wainwright Park, Alta.; Fawn Lake, mouth of Hay River; Mackenzie River, 30 miles above Fort Providence; little lake west end of Great Slave Lake, Mackenzie River district.

Planorbis (Helisoma) trivolvis macrostomus Whiteaves (Baker (8)), several localities in northwestern Ontario; lake northwest of Cormorant Lake, Man.

Planorbis (Helisoma) campanulatus canadensis (Baker and Cahn (9)), Bamaji Lake, Sioux Lookout district, Ont.

Planorbis (Gyraulus) latistomus (Baker (5)), McAree Lake, Rainy River district, Ont.

Planorbis (Gyraulus) circumstriatus Tryon (Baker and Cahn (9)), Winnipeg River, Ont.

Planorbis (Gyraulus) deflectus obliquus DeKay (Baker and Cahn (9)), several localities in Sioux Lookout district, Ont.

Family Physidae

Genus *Physa* Draparnaud 1801

Physa gyrina Say

Physa gyrina Say, J. Phil. Acad. 2 : 171. 1821.

Geographical Range. North America, Alabama and Texas north to Great Slave Lake.

Northernmost record: Great Slave Lake, N. Lat. 62°, Dall (13).

Southernmost record: Texas.

Local Distribution. Previous records: Minaki, Ont., Winnipeg River; Sand and Onion Lakes near Minaki; English River 40 miles north of Minaki; Fox Lake, near Wade; Otter Lake near Minaki, Mozley (21). Ninette, Man., Pelican Lake, Mozley (23). Brereton and Mud Turtle Lakes, Mozley (22). Rainy River, Ont., 1 mile below the Canadian National Railway bridge; Grande Pointe; Onah, Douglas Lake, Man.; Margo, Sask., unnamed lake 1 mile northwest of Whitesand Lake; Kuroki, Fishing Lake; Wadena, Foam Lake; Paskwegin, small lake 2 miles south of Paskwegin siding; Kelliher;

Yonker, Eyehill Creek, Mozley (25). Numerous localities in Jasper National Park, Mozley (26). Sioux Lookout district, Ont., Bamaji, Botsford, Hamilton, Pashkokogan, Cat, Fitchie, Kimmewin, and St. Joseph Lakes, Baker and Cahn (9). Scotsguard, Sask.; Blooming; Beaubier, Russell (36). Tofield, Alta., Beaverhills Lake; Deville, Cooking Lake; Peace River district, Kinuso, Strawberry Creek near Lesser Slave Lake; pond at Mile 200.5, E.D. & B.C. Ry.; Faust, Lesser Slave Lake, Mozley (30). Freshwater and Saltwater Lakes on Charlton Island, James Bay, Richards (35).

Physa gyrina is particularly common on the prairie and parkland, and also occurs in the Rocky Mountain region. In the forested territory it is replaced to a great extent by *P. ancillaria*

Habitat. Lakes and ponds.

Physa gyrina hildrethiana Lea

Physa hildrethiana Lea, Proc. Am. Phil. Soc. 2 : 32. 1841.

Geographical Range. North America, Alabama, Pennsylvania, Illinois, north to Canada.

Northernmost record: Winnipeg, Man. Great Slave Lake (Dall) ?

Southernmost record: Alabama.

Local Distribution. Winnipeg, Catfish Creek, Mozley (23). Pond in Moose Mountain Forest Reserve, Sask.; Phillips, Alta.; Viking, Mozley (30).

Habitat. Temporary ponds and intermittent streams.

Physa ancillaria Say

Physa ancillaria Say, J. Phil. Acad. 5 : 124. 1825.

Geographical Range. North America, New Jersey and Maine, west to Minnesota and Manitoba.

Northernmost record: Madge Lake, north of Kamsack, Sask., N. Lat. 51° 30′.

Southernmost record: "The Ohio River", Baker (3).

Local Distribution. New record: stream entering Lake Nipigon from the east, near Macdiarmid, Ont.

Previous record: Madge Lake.

Habitat. In the larger lakes, and also sometimes in streams. A common habitat is on smooth rock faces exposed to considerable wave action. The specimens from near Macdiarmid were collected just below a small rapid in the stream.

Physa integra Haldeman

Physa integra Haldeman, Mon. No. 3, p. 3. 1841.

Geographical Range. North America, Ohio and South Dakota, north to Manitoba.

Northernmost record: Victoria Beach, Man., N. Lat. 50° 40′.

Southernmost record: Ohio.

Local Distribution. Previous records: Lost and Sword Lakes near Minaki, Ont.; Star Lake near Redditt; Mile 77, G.W.W.D. Ry., Birch River, Man., Mozley (21). Clandeboye, Man., Muckle Creek; Grand Beach, the Grand

Marais; Victoria Beach; Birtle; Birdtail Creek, Mozley (23). Postglacial fossil deposit near Winnipeg, Mozley (31).
Habitat. Lakes and streams.

Genus *Aplexa* Fleming. 1820

Aplexa hypnorum Linné

Bulla hypnorum Linné, Syst. Nat., ed. X, p. 727. 1758.
Geographical Range. Europe, northern Asia, North America.
Northernmost record: (in North America) N. Lat. 69° 40′, W. Long. 141°.
Southernmost record: "South to the vicinity of the Ohio River", Baker (3).
Local Distribution. New records: pond on the Arctic coast of the Yukon Territory at N. Lat. 69° 40′, W. Long. 141°, J. M. Jessup coll.; Bilby, Alta.; Vermilion Lake, Banff, Alta.
Previous records: Camden Bay, Arctic coast; also Demarcation Point; pond on Herschel Island; pond at Collinson Point; brackish pond near Teller; Grantley Harbour; Port Clarence, Alaska; pond near Colville mountains, Victoria Island; lake opposite Bernard Harbour; water hole on tundra at Cape Bathurst, Dall (14). Brereton, Man., Mozley (22). Whiteshell River district, Man., above Jessica Lake; Mallard Lake; Little Whiteshell Lake; *Zizania* marsh below the Whiteshell Lakes; near the Seven Sisters Falls, Winnipeg River; Indian Bay station; Molson; Stony Mountain; Victoria Beach; Treesbank; Steep Rock; Sifton; Yonker, Sask., Eyehill Creek, Mozley (24). Rainy River, Ont.; Grande Pointe, Man.; near Clearwater Lake, Hudson Bay Railway; Birtle; Margo, Sask.; Kuroki, Van Patten Creek, Kuroki Creek; Clair, Clair Creek; Watson, Ironspring Creek; Lanigan; Kelliher; Touchwood, near Hudson Bay Lake, Mozley (25). Lake near Jasper, Alta., Mozley (26). Ponds in Moose Mountain Forest Reserve, Sask.; Lindbrook, Alta.; Deville, Cooking Lake; Peace River district, pond at Mile 200.5, E.D. & B.C. Ry.; creek near Faust; 3 miles north of Spirit River. Postglacial fossil deposits near Winnipeg, and on the shore of the Pasquaia River near The Pas, Man., Mozley (31).
Habitat. Usually in temporary ponds. Occasionally found in lakes and small slow-flowing streams.

Physidae Reported on Good Authority to Occur in Sub-arctic Canada, but not Examined by the Author

Physa jennessi Dall (14). Bernard Harbour, Arctic Canada.
P. johnsoni Clench (12). Hot Sulphur Springs, Banff, Alta.

FAMILY ANCYLIDAE

Genus *Ancylus* Muller 1774

Ancylus coloradensis Henderson

Ancylus coloradensis Henderson, Nautilus, 44 : 31. 1930.
Geographical Range. North America, known from one locality in Colorado, and two in Alberta. Apparently confined to the western mountainous region

Northernmost record: Two small lakes in the Miette Valley, Jasper National Park, Alta., N. Lat. 53°, Mozley (26).
Southernmost record: Eldora Lake, Boulder Co., Colorado.
Local Distribution. The above-mentioned three localities are the only ones known.
Remarks. The occurrence of a member of the genus *Ancylus* in North America is of interest since the group in its modern restricted usage is otherwise confined to Europe and northern Asia.

Genus *Ferrissia* Walker 1903

Ferrissia parallela (Haldeman)

Ancylus parallelus Haldeman, Mon. Pt. 2, p. 3. 1841.
Geographical Range. North America, northern Ohio, Nova Scotia, Ontario, and Manitoba.
Northernmost record: Lake Brereton, Man., N. Lat. 50°.
Southernmost record: northern Ohio. "A species of northern distribution", Baker (3).
Local Distribution. Previous records: Rennie River, near Brereton, Mozley (22). Whiteshell River, Mozley (24). Pashkokogan Lake, Baker and Cahn (9).

Ferrissia rivularis (Say)

Ancylus rivularis Say, J. Phil. Acad. 1 : 125. 1819.
Geographical Range. North America, Ohio and Nebraska north to Canada.
Northernmost record: Birtle, Man., N. Lat. 51° 25′.
Southernmost record: Ohio.
Local Distribution. Previous records: Birdtail Creek, Birtle, Mozley. Post-glacial fossil deposit near Winnipeg, Mozley (31).

Ancylidae Reported on Good Authority to Occur in Sub-arctic Canada, but not Examined by the Author

Ferrissia fusca (C. B. Adams). Bamaji Lake, Sioux Lookout district, Ont., Baker and Cahn (9).

Family Viviparidae

Genus *Campeloma* Rafinesque 1819

Campeloma decisum (Say)

Limnaea decisa Say, Nich. Encyc. I, 1817.
Geographical Range. North America, New England to Manitoba.
Northernmost record: Berens River, above the junction with the Etomami River, N. Lat. 52° 20′.
Southernmost record: Tennessee.
Local Distribution. Previous records: Whiteshell River district, Man., Whiteshell River near first portage below White Lake; between fifth and sixth rapids below Betula Lake; Berens River several miles above the junction

with the Etomami River, Mozley (24). Fort Frances, Ont., Rainy River below the town, also near the town of Rainy River; Grand Beach, Man., the Grand Marais, Mozley (25).

Viviparidae Reported on Good Authority to Occur in Sub-arctic Canada, but not Examined by the Author

Campeloma milesii (Lea). Hamilton Lake, Sioux Lookout district, Ont., Baker and Cahn (9).

Family Valvatidae

Genus *Valvata* Muller 1774

Valvata tricarinata (Say)

Cyclostoma tricarinata Say, J. Phil. Acad. 1 : 13. 1817.
Geographical Range. North America, from Virginia and the Ohio River to Alaska.
Northernmost record: Fort Yukon, N. Lat. 66° 40′.
Southernmost record: Virginia.
Local Distribution. Previous records: Mackenzie River district, south shore Second Lake, Horn River; southwest side of Mackenzie River 30 miles above Fort Providence; western end of Lake Kakisa; south shore of Lake Kakisa near mouth of Kakisa River, Whittaker (39). St. Norbert, Man., La Salle River; Clandeboye, Muckle Creek; Victoria Beach; Treesbank, Souris River; Theodore, Sask., Whitesand River, Mozley (23). Malachi, Ont., Malachi Lake; Whiteshell River district, Man., Betula Lake; between sixth and seventh rapids below Betula Lake; Morris, Morris River; Delta; Ninette, Bone Lake; Clearwater (Atikameg) Lake, Hudson Bay Railway; Yonker, Sask., Manitou Lake (empty shells only), Mozley (24). Madge Lake north of Kamsack, Sask., Mozley (25). Sioux Lookout district, Ont., outlet of Bamaji Lake, Fitchie, Kimmewin, Botsford, and Cat Lakes, Baker and Cahn (9). Deville, Alta., Cooking Lake; Wabamun, Lake Wabamun, Mozley (30). Post-glacial fossil deposit near Winnipeg, and also near Portage la Prairie and Lavenham, Man., Mozley (31). Moose Factory, Ont., Butler and Charles Islands (recent and fossil), Shipsands Island, James Bay, Richards (35).
Habitat. Usually found in lakes, especially in shallow water, sometimes in large ponds and marshes.

Valvata lewisi Currier

Valvata lewisi Currier, Kent Sci. Inst. Misc. Pub., No. 1, p. 9. 1868.
Geographical Range. North America, the northern part of the continent from the Atlantic to the Pacific.
Northernmost record: Bernard Harbour, N. Lat. 68°.
Southernmost record: "Southward range not fully known." Baker.
Local Distribution. Previous records: Arctic Coast, creek at Bernard Harbour; lake near Point Williams, Victoria Island, Dall (14). South shore Fawn and Second Lakes, Horn River, Mackenzie River district; southwest side Mackenzie River 30 miles above Fort Providence; south shore Great

Slave Lake near Sulphur Point, Whittaker (39). Numerous localities in Jasper National Park, Alta., Mozley (26). Postglacial fossil deposit on the shore of the Pasquaia River near The Pas, Man., Mozley (31).
Habitat. Usually in marshes surrounding relatively large bodies of water.

Valvata lewisi helicoidea Dall

Valvata lewisi var. *helicoidea* Dall, Harriman Alaska Exped. 13 : 123. 1905.
Geographical Range. North America, said to occur with the typical *lewisi* throughout its range.
Northernmost record: Fort Yukon, Alaska, N. Lat. 66° 49′.
Southernmost record: Oneida Lake, New York.
Local Distribution. Previous records: Mackenzie River district, south shore Second Lake, Horn River; western end Lake Kakisa; Mills Lake at mouth of Horn River; south side Mills Lake, Whittaker (39). Lake Winnipeg, C. H. O'Donoghue coll., Baker (3). Kimmewin Lake, Sioux Lookout district, Baker and Cahn (9).

Valvatidae Reported on Good Authority to Occur in Sub-arctic Canada, but not Examined by the Author

Valvata tricarinata perconfusa Walker, Baker and Cahn (9), outlet of Bamaji Lake, Sioux Lookout district, Ont.

Family Amnicolidae

Genus *Amnicola* Gould and Haldeman 1841

Amnicola limosa (Say)

Paludina limosa Say, J. Phil. Acad. 1 : 125. 1817.
Geographical Range. North America, Texas to New England, Manitoba (and northward ?).
Northernmost record: Lake la Loche, N. Lat. 56° 30′, Dall (13) = *limosa?*
The northernmost source of shells seen by the writer is near Winnipeg, Man., (postglacial fossils, Mozley (31)).
Southernmost record: Texas.
Local Distribution. Previous records: Winnipeg; Lake Brereton *(limosa?)* Mozley (22).

Amnicola limosa porata (Say)

Paludina porata Say, J. Phil. Acad. 2 : 174. 1821.
Geographical Range. North America, Illinois to Manitoba. Limits of range not known.
Local Distribution. Previous records: Lake Winnipeg, Victoria Beach, Man., Mozley (24). Sioux Lookout district, Ont., Pashkokogan, Hamilton, Kapikik, Cat, Botsford and Kimmewin Lakes, Baker and Cahn (9). Upper Tintah or Norcross Beach of Glacial Lake Agassiz near Lavenham, Man., Mozley (31).

Amnicola walkeri Pilsbry

Amnicola walkeri Pilsbry, Nautilus, 12 : 43. 1898.

Geographical Range. North America, from Ottawa, Ont., to Lake Michigan and Manitoba.

Northernmost record: Lake Winnipeg, Man.

Southernmost record: Lake Michigan ?

Local Distribution. Previous records: Victoria Beach, Lake Winnipeg, Mozley (24). Kimmewin Lake, Sioux Lookout district, Ont., Baker and Cahn (9). Upper Tintah or Norcross Beach of Glacial Lake Agassiz near Lavenham, Man., Mozley (31).

Amnicola winkleyi mozleyi Walker

Amnicola winkleyi mozleyi Walker, Nautilus, 39 : 6. 1925.

Geographical Range. North America, Manitoba and Ontario.

Northernmost record: Winnipeg, Man.

Local Distribution. Previous records: two postglacial deposits near Winnipeg, Mozley (31).

Remarks. A shell which closely resembles this variety was collected in the La Salle River at St. Norbert, Man., but as it is a single specimen it appears best not to cite this as a definite locality until further collections are made.

Amnicola (Cincinnatia) emarginata (Küster)

Paludina emarginata Küster, Paludina, Conch. Cab. p. 50. 1852.

Geographical Range. North America, Kentucky and Arkansas north to Canada.

Northernmost record: "N. Lat. 51° on Hudson Bay", Dall (13).

The northernmost source of shells examined by the writer is Winnipeg, Man.

Southernmost record: Arkansas.

Local Distribution. Previous records: Mackenzie River district, southwest side of Mackenzie River 30 miles above Fort Providence; south shore Lake Kakisa, near mouth of the Kakisa River; south shore Great Slave Lake near Sulphur Point; south side Mills Lake, Whittaker (39). Postglacial fossil deposit near Winnipeg, Mozley (31).

Amnicolidae Reported on Good Authority to Occur in Sub-arctic Canada but not Examined by the Author

Amnicola lustrica decepta Baker, Botsford Lake, Sioux Lookout district, Ont., Baker and Cahn (9).

Amnicola (Cincinnatia) cincinnatiensis judayi Baker, Hamilton Lake, Sioux Lookout district, Ont., Baker and Cahn (9).

Amnicola (Cincinnatia) emarginata canadensis (Baker), Beaver Lake and Little Lake, Mackenzie River district, Baker (3).

Class PELECYPODA

FAMILY SPHAERIDAE

All the species of this family which are listed below were identified by the late Dr. Victor Sterki. The records of Baker and Cahn (9) are included, but not those of other earlier authors. It should be noted that Baker and Cahn's material was also examined by Sterki. As there is little reliable information in the literature regarding the range of the members of this family, no geographical notes are given.

Genus *Sphaerium* Scopoli 1777

Sphaerium sulcatum (Lamarck)

Cyclas sulcata Lamarck, An. sans Vert. 5 : 560. 1818.
Local Distribution. Previous records: Indian Bay station, Man., Falcon Bay; Rainy Lake, mile east of Wade, Ont., Mozley (21). Theodore, Sask., Whitesand River, Mozley (23). Sioux Lookout district, Ont., Botsford Lake, Baker and Cahn (9). Postglacial deposits near Lavenham, Man., Mozley (31).

Sphaerium crassum Sterki

Sphaerium crassum Sterki, Nautilus, 14 : 140. 1910.
Local Distribution. Backwater of the Winnipeg River, near Minaki, Ont.; Falcon Bay, Shoal Lake, Man., Mozley (21).

Sphaerium solidulum (Prime)

Cyclas solidula Prime, Proc. Boston Soc. Nat. Hist. 4 : 158. 1851.
Local Distribution. Previous records: Mackenzie River district, western end of Lake Kakisa, Whittaker (39). Whitemouth River, Man., near its junction with the Winnipeg River, Mozley (21). Postglacial fossil deposit near Winnipeg, Mozley (31).

Sphaerium stamineum (Conrad)

Cyclas staminea Conrad, Am. J. Sci. 25 : 342. 1834.
Local Distribution. Postglacial deposit near Winnipeg, Man., Mozley (31).

Sphaerium emarginatum (Prime)

Cyclas emarginata Prime, Proc. Boston Soc. Nat. Hist. 4 : 156. 1851.
Local Distribution. Hamilton Lake, Sioux Lookout district, Ont., Baker and Cahn (9); postglacial deposit near Winnipeg, Man., Mozley (31).

Sphaerium torsum Sterki

Sphaerium torsum Sterki, Annals Carnegie Mus. 10 : 434. 1916.
Local Distribution. Postglacial deposit near Winnipeg, Man., Mozley (31).

Sphaerium acuminatum (Prime)

Cyclas acuminata Prime, Proc. Boston Soc. Nat. Hist. 4 : 155. 1851.
Local Distribution. Victoria Beach, Lake Winnipeg, Man., Mozley. Postglacial deposit near Winnipeg, Man., Mozley (31).

Sphaerium vermontanum Prime

Sphaerium vermontanum Prime, Proc. Acad. Nat. Sci. Phila. p. 128. 1861.
Local Distribution. Previous records: Mackenzie River district, western end of Lake Kakisa, Whittaker (39). Sioux Lookout district, Ont., Botsford Lake, Baker and Cahn (9).

Sphaerium striatinum (Lamarck)

Cyclas striatina Lamarck, An. sans Vert. 5 : 560. 1818.
Local Distribution. Previous records: Mackenzie River district, western end of Lake Kakisa, Whittaker (39). Whitemouth River, Man., near its junction with the Winnipeg River, Mozley (21). Postglacial fossil deposit near Winnipeg, Mozley (31).

Sphaerium occidentale Prime

Sphaerium occidentale Prime, Proc. Acad. Nat. Sci. Phila. p. 295. 1860.
Local Distribution. Ditch near Mile 69, G.W.W.D. Ry., Man., Mozley (21).

Sphaerium tenue (Prime)

Cyclas tenuis Prime, Proc. Boston Soc. Nat. Hist. 4: 161. 1851.
Local Distribution. Previous records: Mackenzie River district, south shore Second Lake, Fawn River; southwest side of Mackenzie River 30 miles above Fort Providence; south shore of Lake Kakisa near mouth of the Kakisa River; south side of Mills Lake, Whittaker (39). Traverse Bay, near Victoria Beach, Lake Winnipeg, Man., Mozley (23). Sioux Lookout district, Ont., Bamaji Lake, Baker and Cahn (9).

Sphaerium notatum Sterki

Sphaerium notatum Sterki, Nautilus, 41 : 55. 1927.
Local Distribution. Postglacial deposit near Winnipeg, Man., Mozley (31).

Genus *Musculium* Link 1907

Musculium transversum (Say)

Cyclas transversa Say, New Harmony Diss. 2 : 356. 1829.
Local Distribution. Previous records: Matlock, Lake Winnipeg, Man., Mozley (23). Postglacial deposit near Winnipeg, Mozley (31).

Musculium truncatum (Linsley)

Cyclas truncata Linsley, Am. J. Sci. 6 : 234. 1848.
Local Distribution: Previous records: Hamilton Lake, Sioux Lookout district, Ont.; Skunk Lake, near Minaki, Ont., Mozley (21); marsh bordering Lake Winnipeg, near Victoria Beach, Man., Mozley (23).

Musculium rosaceum (Prime)

Cyclas rosacea Prime, Proc. Boston Soc. Nat. Hist. 4 : 155. 1851.
Local Distribution. Previous records: Mackenzie River district, south side Mills Lake, Whittaker (39). Sioux Lookout district, Ont., St. Joseph,

Botsford, Hamilton, Kimmewin, Kapikik and Pashkokogan Lakes, Baker and Cahn (9).

Musculium ryckholti (Normand)

Cyclas ryckholti Normand, Notes sur Quelques Nouvelles Cyclades, p. 7. 1844.
Local Distribution. Previous records: marsh on shore of Lake Winnipeg at Victoria Beach, Man.; small lake 1 mile northeast of Ninette Sanitorium, Ninette, Man., Mozley.

Musculium securis (Prime)

Cyclas securis Prime, Proc. Boston Soc. Nat. Hist. 4 : 160. 1851.
Local Distribution. Previous records: Alice Lake, between Minaki and Wade, Ont., Mozley (21). Lake Brereton, Man., Mozley (22). Sioux Lookout district, Ont., Fitchie Lake, Baker and Cahn (9).

Genus *Pisidium* C. Pfeiffer 1821

Pisidium compressum Prime

Pisidium compressum Prime, Proc. Boston Soc. Nat. Hist. 4 : 161. 1851.
Local Distribution. South side Mills Lake, Mackenzie River district, Whittaker (39). Birdtail Creek near Birtle, Man.; Whitesand River near Theodore, Sask., Mozley (23). Lake Annette near Jasper, Alta.; Lake No. 2 near Geikie, Alta., Mozley (26). Postglacial deposit near Winnipeg, Man., Mozley (31). *P. compressum* var. Pashkokogan and Botsford Lakes, Sioux Lookout district, Ont., Baker and Cahn (9).

Pisidium fallax Sterki

Pisidium fallax Sterki, Nautilus, 10 : 20. 1896.
Local Distribution. Whitesand River near Theodore, Sask., Mozley (23). Postglacial deposit near Winnipeg, Man., Mozley (31).

Pisidium punctatum Sterki

Pisidium punctatum Sterki, Nautilus, 7 : 99. 1895.
Local Distribution. Hamilton Lake, Sioux Lookout district, Ont., Baker and Cahn (9).

Pisidium variabile Prime

Pisidium variabile Prime, Proc. Boston Soc. Nat. Hist. 4 : 163. 1851.
Local Distribution. Lake No. 5 near Geikie, Alta., Mozley (26). Botsford Lake, Sioux Lookout district, Ont., Baker and Cahn (9).

Pisidium variabile brevius Sterki

Pisidium variabile brevius Sterki, Nautilus, 19 : 118. 1906.
Local Distribution. Hibernia Lake and Caledonia Creek, near Jasper, Alta., Mozley (26).

Pisidium minusculum Sterki

Pisidium minusculum Sterki, Nautilus, 20 : 17. 1906.
Local Distribution. Kimmewin Lake, Sioux Lookout district, Ont., Baker and Cahn (9).

Pisidium adamsi Prime

Pisidium adamsi Prime, Smithsonian Misc. Coll. 145 : 16. 1865.
Local Distribution. Lake Brereton, Man., Mozley (22). Cat and Fitchie Lakes, Sioux Lookout district, Ont., Baker and Cahn (9).

Pisidium neglectum Sterki

Pisidium neglectum Sterki, Nautilus, 20 : 87. 1906.
Local Distribution. Jacques Lake, and the stream which drains it (*not* Jacques Creek), Rocky River drainage, northeast of Jasper, Alta., Mozley (26).

Pisidium scutellatum Sterki

Pisidium scutellatum Sterki, Nautilus, 10 : 66. 1896.
Local Distribution. Mackenzie River district, south shore of Fawn and Second Lakes, Horn River; southwest side of Mackenzie River 30 miles above Fort Providence; south shore Lake Kakisa, near mouth of the Kakisa River; south side Mills Lake, Whittaker (39). Lakes Annette and Patricia, near Jasper, Alta., Mozley (26). Bamaji, Hamilton, Pashkokogan and Kimmewin Lakes, Sioux Lookout district, Ont., Baker and Cahn (9).

Pisidium roperi Sterki

Pisidium roperi Sterki, Nautilus, 12 : 77. 1898.
Local Distribution. Pond near Mud Turtle Lake, Man., Mozley (22). Marsh on shore of Lake Winnipeg, near Victoria Beach, Mozley (23). Lake No. 8, near Jasper, Alta., Mozley (26).

Pisidium subrotundum Sterki

Pisidium subrotundum Sterki, Nautilus, 20 : 19. 1906.
Local Distribution. Small lake near Ninette, Man., Mozley (23).

Pisidium splendidulum Sterki

Pisidium splendidulum Sterki, Nautilus, 11 : 113. 1898.
Local Distribution. Lake No. 10, near Jasper, Alta., Mozley (26).

Pisidium tenuissimum Sterki

Pisidium tenuissimum Sterki, Nautilus, 14 : 99. 1901.
Local Distribution. Skunk Lake, near Minaki, Ont., Mozley (21). Lake Edith and the larger Trefoil Lake, near Jasper, Alta., Mozley (26).

Pisidium rotundatum Prime

Pisidium rotundatum Prime, Proc. Boston Soc. Nat. Hist. 4 : 164. 1851.
Local Distribution. Hamilton and Kimmewin Lakes, Sioux Lookout district, Ont., Baker and Cahn (9).

Pisidium ferrugineum Prime

Pisidium ferrugineum Prime, Proc. Boston Soc. Nat. Hist. 4 : 162. 1851.
Local Distribution. Hamilton Lake, Sioux Lookout district, Ont., Baker and Cahn (9).

Sphaeriidae Reported on Good Authority to Occur in Sub-arctic Canada, but not Examined by the Author (Identifications by Sterki)

Sphaerium tumidum Baird, south shore Great Slave Lake, near Sulphur Point (?); near Fort Wrigley, Mackenzie River district, Whittaker (39).
Musculium jayense Prime, south shore Fawn Lake, Horn River, Mackenzie River district, Whittaker (39).
Pisidium indianense Sterki, south shore Second Lake, Horn River; at mouth of the Hay River, Mackenzie River district, Whittaker (39).

Family Unionidae

Genus *Quadrula* Rafinesque 1820

Quadrula quadrula Rafinesque

Obliquaria (Quadrula) quadrula Rafinesque, Ann. Sci. Phys. Bruxelles, 5 : 307. 1820.
Geographical Range. North America, the Mississippi and St. Lawrence drainages; Canada east of the Rocky Mountains.
Northernmost record: Red River at Winnipeg.
Southernmost record: eastern Texas.
Local Distribution. Red River at Winnipeg.

Genus *Amblema* Rafinesque 1819

Amblema costata (Rafinesque)

Amblema costata Rafinesque, Ann. Sci. Phys. Bruxelles, 5 : 315. 1820.
Geographical Range. North America, the Mississippi and St. Lawrence drainages; Canada east of the Rocky Mountains.
Northernmost record: Saskatchewan River, Lake Winnipeg.
Southernmost record: Alabama River ? Southern distribution imperfectly known.
Local Distribution. New record: near the Englishman's Rapid, Berens River, Man., at a depth of 12 metres.
Previous records: Red, and Black Rivers, Man.

Genus *Fusconaia* Simpson 1900

Fusconaia flava (Rafinesque)

Obliquaria flava Rafinesque, Ann. Sci. Phys. Bruxelles, 5 : 305. 1820.
Geographical Range. North America, the Mississippi drainage; Canada east of the Rocky Mountains.
Northernmost record: Nelson River, Man.
Southernmost record: West Virginia ?
Local Distribution. Red, Roseau, Souris, and Nelson Rivers; Lake Winnipeg.

Genus *Strophitus* Rafinesque 1820

Strophitus rugosus (Swainson)

Anodon rugosus Swainson, Zool. Ill., Ser. I, II, pl. 96. 1822.

Geographical Range. North America, the Mississippi drainage; Canada east of the Rocky Mountains.
Northernmost record: mouth of the Hay River, N. Lat. 60° 51′.
Southernmost record: Arkansas.
Local Distribution. New record: Birdtail Creek, near Birtle, Man.
Previous records: Red, Whitemouth and Saskatchewan Rivers; Lake Winnipeg; Playgreen Lake.
Fossil records: Lake Agassiz clay near Mile 93, G.W.W.D.Ry., Man.; postglacial gravel bed near Birtle, Man.
Remarks. Baker (3) states that specimens from Arkansas and elsewhere belong to the variety *pavonius* of Lea.

Genus *Anodonta* Lamarck 1799

Anodonta grandis Say

Anodonta grandis Say, New Harmony Diss. 2 : 341. 1829.
Geographical Range. North America, Mississippi drainage and upper St. Lawrence drainage; Canada east of the Rocky Mountains.
Northernmost record: Lake Winnipeg ?
Southernmost record: Texas.
Local Distribution. New record: Morris River, near Morris, Man. Previously reported from the Fairford River and other localities, most of the records probably being based upon the sub-species mentioned below.

Anodonta grandis footiana Lea

Anodonta footiana Lea, Proc. Am. Phil. Soc. 1 : 289. 1840.
Geographical Range. North America, Mississippi drainage; Canada east of the Rocky Mountains.
Northernmost record: Lake Kakisa, N.W.T., N. Lat. 61°.
Southernmost record: Michigan ?
Local Distribution. New record: Birdtail Creek near Birtle, Man.
Previous records: numerous lakes in far western Ontario; Red and Souris Rivers, Man.; Battle River Lake, Alta.
Fossil record: postglacial gravel bed near Birtle.
Remarks. The records of *A. grandis* from Lake Winnipeg may refer to this variety.

Anodonta kennicotti Lea

Anodonta kennicotti Lea, Proc. Phil. Acad. 5 : 56. 1861.
Geographical Range. North America, St. Lawrence, Hudson Bay, and Mackenzie drainages.
Northernmost record: outlet of Lake Winnipeg.
Southernmost record: Lake of the Woods ?
Local Distribution. New records: Lake Brereton, Man. (previously reported as *A. grandis footianc*); Lake Winnipegosis.
Previous records: numerous lakes and streams in far western Ontario; Lakes Winnipeg and Manitoba; Grand Rapids of the Saskatchewan; Ekwan River, Keewatin.

Genus *Anodontoides* Simpson 1898

Anodontoides ferussacianus (Lea)

Anodonta ferussaciana Lea, Trans. Am. Phil. Soc. 5 : 45. 1834.
Geographical Range. North America, Mississippi and St. Lawrence drainages; Canada east of the Rocky Mountains.
Northernmost record: Whitesand River, near Theodore, Sask.
Southernmost record: Tennessee.
Local Distribution. New record: Whitesand River, as above.
Previous records: Lake of the Woods; Lake Winnipeg.

Genus *Lasmigona* Rafinesque 1831

Lasmigona complanata katherinae (Lea)

Unio katherinae Lea, Syn., p. 35. 1838.
Geographical Range. North America, the northern part of the Mississippi drainage?, Lake Superior, and Canada east of the Rocky Mountains; Hudson Bay drainage.
Northernmost record: Lake Winnipeg; "Nelson River drainage", Dall.
Southernmost record: Lake Superior; northern part of Mississippi drainage?
Local Distribution. New records: Birdtail Creek near Birtle, Man.; Moose Jaw Creek near Moose Jaw, Sask.
Previous records: Winnipeg River at Minaki; Lake of the Woods, Ont.; Roseau, Souris, Red, Assiniboine, and Nelson Rivers, Man.; Lake Winnipeg; lower Saskatchewan River, Shoal, Shell, and Battle Rivers, Battle River Lake, Alta.; Carrot River near Arborfield, Sask.
Previous fossil record: postglacial gravel bed near Birtle.

Lasmigona compressa (Lea)

Symphynota compressa Lea, Trans. Am. Phil. Soc. 3 : 450. 1829.
Geographical Range. North America, New York to Nebraska, and from Kentucky to Manitoba and Saskatchewan.
Northernmost record: Carrot River near Arborfield, Sask.
Southernmost record: Kentucky.
Local Distribution. New fossil record: postglacial gravel bed near Birtle, Man.
Previous records: Boulder and Missinaibi Rivers, Ont.; Carrot River.
Remarks. This species has been reported from the Sheyenne River south of Devils Lake, North Dakota, by Winslow (40). This stream is in the drainage basin of the Red River.

Genus *Proptera* Rafinesque 1819

Proptera alata megaptera (Rafinesque)

Metaptera megaptera Rafinesque, Ann. Sci. Phys. Bruxelles, 5 : 307. 1820.
Geographical Range. North America, Mississippi and (in part) Atlantic drainages; Canada east of the Rocky Mountains.

Northernmost record: Red River, Man.
Southernmost record: northern Alabama.
Local Distribution. Previous records: near Lake of the Woods, Ont.; Red River.
Remarks. Following Baker (3), the above name is used for the species formerly known as *Lampsilis alatus* (Say).

Genus *Actinonaias* Fischer and Crosse 1893

Actinonaias carinata (Barnes)

Unio carinatus Barnes, Am. J. Sci. 6 : 259. 1823.
Geographical Range. North America, Mississippi drainage; Canada east of the Rocky Mountains; for details of range in the vicinity of the Great Lakes see Baker (3, p. 221).
Northernmost record: Assiniboine River, Man.
Southernmost record: southern Michigan; Arkansas ?
Local Distribution. New record: Assiniboine River at Treesbank, Man.
Previous records: Roseau River; Assiniboine River at Millwood, Man.

Genus *Ligumia* Swainson 1840

Ligumia recta latissima (Rafinesque)

Unio latissima Rafinesque, Ann. Sci. Phys. Bruxelles, 5 : 297. 1820.
Geographical Range. North America, Mississippi and Atlantic drainages; western Canada east of the Rocky Mountains.
Northernmost record: Red River, Man.
Southernmost record: Georgia and Arkansas.
Local Distribution. New record: Assiniboine River at Aweme, Man.
Previous records: Lake of the Woods, Ont.; Roseau, Red, and Assiniboine Rivers, Man.
Fossil record: postglacial gravel bed near Birtle, Man.

Genus *Lampsilis* Rafinesque 1820

Lampsilis ventricosa (Barnes)

Unio ventricosus Barnes, Am. J. Sci. 6 : 267. 1823.
Geographical Range. North America, Mississippi and Atlantic drainages; Canada east of the Rocky Mountains.
Northernmost record: Nelson River, Man.
Southernmost record: Oklahoma.
Local Distribution. New record: Nelson River, at the point where the Hudson Bay Railway crosses that stream for the first time north of The Pas, Man.
Previous records: Roseau and Red Rivers; Lake Winnipeg.
Previous fossil record: postglacial gravel bed near Birtle, Man.
Remarks. *L. ventricosa* is represented in this part of North America by a dwarf variety, but no useful purpose would be served, at least for the present, by describing it as a new sub-species.

Baker (3) regards the great majority of the previous records of this species in Wisconsin as belonging to the variety *occidens* (Lea). Having examined the type specimen of this variety in the collection of the United States National Museum in conjunction with his own and other specimens, the author is not convinced that it is a distinct race.

Lampsilis siliquoidea rosacea (De Kay)

Unio rosacea De Kay, Zool. N.Y. 5 : 192. 1843.
Geographical Range. North America, Mississippi and Atlantic drainages; Canada east of the Rocky Mountains.
Northernmost record: Great Slave Lake.
Southernmost record: northern Indiana.
Local Distribution. New records: Whiteshell River, several localities below Betula Lake; Birdtail Creek near Birtle; Valley River, 1 mile above its mouth; Mossy River near Lake Winnipegosis; Lake Winnipegosis, all in Manitoba.
Previous records: this species has been reported from many localities throughout western Canada to the east of the Rocky Mouutains.
Remarks. Gravid specimens were collected in Birdtail Creek on November 11, 1924, and in the Red River near Winnipeg on November 1, 1925.

Lampsilis superiorensis (Marsh)

Unio superiorensis Marsh, Nautilus, 10 : 103. 1897.
Geographical Range. North America, from the region of Lake Superior to the Mackenzie River district.
Northernmost record: Lake Kakisa, N. Lat. 61°.
Southernmost record: the upper Great Lakes region.
Local Distribution. Previous records: numerous localities in far western Ontario. Lake Kakisa, and the mouth of the Hay River, Mackenzie River district, Whittaker (39).

Unionidae Reported on Good Authority to Occur in Sub-arctic Canada, but not Examined by the Author

Anodonta marginata Say, Schist Lake, Sioux Lookout district, Ont., Baker and Cahn (9). This locality is in the Hudson Bay drainage. It is of interest as possibly indicating a westward migration of this characteristic Atlantic coast species. Baker and Cahn state that the single specimen collected was typical in form and color.

The Local Distribution of the Molluscan Fauna

The general procedure in this work has been to ascertain the types of habitat which are available in this region for settlement by molluscs, and then to observe the distribution of the species in them. It has been considered desirable to define briefly the position which this part of Canada occupies with reference to the adjoining regions. A brief summary of the various zoogeographical sub-divisions of North America is therefore given.

In most of the previous work on the flora and fauna of North America, attention has been directed chiefly to the details of distribution rather than to general geographical considerations. It may not be out of place to devote a paragraph to showing that the various schemes of classification which have been proposed are not mutually exclusive, as has sometimes been supposed, but are complementary.

The Zoogeographical Sub-divisions of North America

It is now generally agreed among biologists and geographers that North America forms a distinct zoogeographical region. Regarding the sub-division of this continent however, there is wide divergence of opinion. These differences appear to have arisen, at least in part, from the diverse points of view from which the subject has been approached. The "Life Zones" of Merriam (19) afford an example, being based upon a conception very similar to that of the "heat budget," *i.e.*, the total quantity of heat required to produce mature individuals of a given organism and to ensure reproduction. Merriam's Life Zones have the disadvantage of being somewhat arbitrary and inflexible. A useful alternative division of the continent is into Arctic, Sub-arctic, and Temperate belts or regions. This takes into account the facts which formed the basis of the division of North America into Holarctic and Sonoran portions by Lydekker (18), and there can be little doubt that there is a change in the character of the fauna of the continent in the neighborhood of N. Lat. 50°. Those who approach the subject from the standpoint of ecology place much importance upon the natural developmental cycles of the vegetation, and the associated changes in the fauna. It is also desirable that the existence of widespread natural regions or prevailing landscape types should be kept in mind. According to this conception, the northern part of the continent at least may be divided into a number of natural areas, in which the climate, soils, flora, and fauna are similar within sufficiently narrow limits to give the country an essential homogeneity and characteristic appearance. Examples of these natural regions are the barren ground, northern coniferous forest, parkland, and prairie. It is likely that there is a degree of truth in each of these viewpoints.

The region dealt with in this account lies in the sub-arctic region, covers four natural regions or major landscape types, and includes four of Merriam's Life Zones. A consideration of some of the habitats of this region from a developmental standpoint is to be found in the work of Bird (10).

Types of Habitat Found in Sub-arctic Canada and Their Molluscan Fauna

Up to the present, most of the published accounts relating to the freshwater mollusca of this region have been in the nature of faunal lists. Little attention has been paid to the local distribution of the species. Several studies of the habitat relationships of the mollusca have been made in the United States, but only one short account has been published of such work,

carried out within a radius of several hundred miles, in western Canada. Most investigations in other parts of the world have been concerned with the distribution of the mollusca in a single body of water, and the geographical aspects of the subject have been neglected. Although much important information has resulted from ecological studies, many of them tend to convey an impression, whether intentionally or not, of the existence of a high degree of uniformity in the fauna of many types of aquatic habitats. This is erroneous. The fauna of such situations is not stereotyped, nor is the association of the various species a haphazard affair. In another paper (Mozley (34)) it has been demonstrated that this association may be the result of definite, though complex reactions, and can be measured and mathematically expressed. The diversity in the constitution of the fauna of similar habitats is very noticeable throughout the sub-arctic region. Under different geographical conditions it is apparently possible for one species to occupy the position of another in the environmental complex, with considerable precision. This probably involves the substitution of the one species for the other in the food chains. Investigations along these lines promise interesting results.

Within the territory included in the scope of this paper there are four well-marked natural regions, known as the Prairie, Parkland, Forest, and Barren Ground. These are comparable respectively to the Steppe, Forest-Steppe, Taiga, and Tundra of northern Asia.

The Prairie, which is situated along the southern boundary of western Canada, is characterized by the predominance of grassy vegetation and the absence of trees. Many of the large lakes of this region are saline, and the most favorable habitats for fresh-water mollusca are small marshy lakes. Ponds are numerous, but, as a result of the semi-arid climate, many of them contain water only during the spring of each year.

The Parkland, which is found to the north of the Prairie, is a narrow belt of groves of aspen *(Populus tremuloides)* with intervening grassy glades. As far as fresh-water organisms are concerned, conditions on the Parkland are very similar to those on the Prairie, but many of the Parkland waters are less saline. Ponds are somewhat more numerous, and they contain water for a longer period each year than do those on the Prairie. The general conditions of life in these two regions closely resemble those on the Steppe of northern Kazakstan, and the Forest-Steppe of Siberia. For the most part, the species of animals which occupy similar situations in Asia and North America are different, although frequently of the same or related genera. Ecologically they are closely comparable.

The Forest, which forms a broad belt running across the whole of the country from Ungava to the Rocky Mountains, presents conditions which are unlike those of the Prairie and Parkland. The waters of this area are neutral or acid in reaction. In many instances they have a low content of dissolved mineral salts, and are relatively rich in organic matter. *Sphagnum* invades many of the smaller bodies of water in this region and appears to have an unfavorable effect upon the molluscan fauna, or at least to be associated with

such an effect. In this respect many of the small lakes and ponds of this region resemble those of northern Sweden and Finland. It is a notable fact that when such waters are aërated, as in streams with rapids and falls, they appear to be capable of supporting a much richer molluscan fauna. Large rock-bound lakes with clear and cold waters are not uncommon in the forested region, and they have a characteristic molluscan fauna.

The Barren Ground, which lies to the north of the forested area along the Arctic coast of Canada, is a treeless area which closely resembles the Tundra of Fennoscandia and Siberia. Several fresh-water mollusca are found in this region in abundance.

The habitats of fresh-water mollusca in sub-arctic Canada may be grouped under seven descriptive headings, namely:

(i) Temporary ponds.
(ii) Ponds which contain water permanently, and small shallow lakes.
(iii) Large lakes having outlet streams.
(iv) Lakes without direct outlet streams.
(v) Intermittent streams.
(vi) Permanent streams of the non-mountainous region.
(vii) Streams of the Rocky Mountain region.

This grouping of habitats is somewhat arbitrary, and takes no account of the fact that each pond, lake and stream has its own individual characteristics. There are also numerous habitats which are not easily placed in one of the above classes. Nevertheless it is desirable to have clear-cut conditions as the basis of the classification, even though this tends in some instances to exaggerate the importance of extreme conditions.

The plan of presentation adopted in the following account is to give a brief description of some of the salient features of the principal habitat types, with comments on their fauna in other parts of the sub-arctic region. This is followed by a series of concrete examples in which the molluscan fauna of certain specific localities is listed. It should be borne in mind that these molluscan associations are not necessarily typical, but taken as a whole they are believed to be representative. All the information is original and has been drawn from a large number of observations.

Temporary Ponds

The presence of a large number of small, shallow ponds is characteristic of many parts of the Prairie and Parkland. These usually occupy little depressions in which water from the melting snow collects in the spring, and remains through the months of April, May, and in some instances a part of June. After this they are dry until the following spring. Such ponds are characterized by a short aquatic phase in the spring followed by progressively drier conditions, and are subject to low temperatures during the winter. A description of the aquatic fauna and general conditions in one pond of this type has already been published (Mozley, 27). Similar ponds occur on the Steppe and Forest-Steppe of northern Asia. It may be worth noting that such

ponds in Canada and Siberia draw most of their water supply from melting snow, and this may be of significance in comparing similar habitats in South Africa and Australia which are fed by rains.

Apart from certain molluscs, namely *Planorbis umbilicatellus*, and *Planorbula campestris*, the animals which are most characteristic of these situations in Canada are phyllopod crustacea such as *Lepidurus*, *Branchipus*, *Limnetis*, and *Estheria*.

Examples

1. A small pond between Lake Brereton and Mud Turtle Lake, eastern Man. *Aplexa hypnorum*.
2. A small pond near the shore of Mud Turtle Lake. *Planorbis umbilicatellus*.
3. A small pond near Stony Mountain, Man. *Lymnaea palustris*, *Aplexa hypnorum*.
4. A pond 4 miles southwest of Winnipeg, Man. *Lymnaea caperata*, *Planorbula campestris*, *Aplexa hypnorum*.
5. A pond near Spirit River, Alta. *Lymnaea palustris*, *L. caperata*, *Planorbis umbilicatellus*, *Aplexa hypnorum*.
6. A pond near St. Vital, Man. *Lymnaea palustris*, *L. caperata*, *Planorbis exacuous*, *P. umbilicatellus*, *Planorbula campestris*, *P. crassilabris*, *Aplexa hypnorum*.

Small Fresh-water Lakes and Ponds

Under this heading are included ponds which contain water permanently, and small pond-like lakes. In regions where there are few outcrops of the bedrock, such bodies of water generally have low muddy shores, and are invaded to a greater or less extent by marsh plants such as *Scirpus* and *Typha*. Under these conditions the predominant molluscs are *Lymnaea stagnalis jugularis*, *L. palustris*, *Planorbis trivolvis*, and *Physa gyrina*. In parts of the forested regions the lakes have rocky shores, and under these conditions the tendency towards marsh development is less marked. The species found most commonly in these rock-bound lakes are *Planorbis campanulatus wisconsinensis*, *P. corpulentus*, and *Physa ancillaria*. In shallow places where there is decaying vegetable matter *Lymnaea megasoma* is sometimes to be found in abundance. A particular type of pond, formed by beavers (*Castor canadensis*) is of considerable local importance as a habitat for molluscs in the Rocky Mountain area (Mozley (28)).

The small lakes of Canada closely resemble those of Siberia. In the forested part of the latter country, however, a greater proportion of the small basins are filled to such an extent with vegetation that they are no longer suitable habitats for fresh-water mollusca. Ponds on the flood plains of streams are less important habitats for mollusca in Canada than in northern Asia. Among the fresh-water gastropods which are common to these two countries are *Lymnaea stagnalis* and *L. palustris*. The species which in Canada most frequently accompanies *L. stagnalis* in ponds and small lakes is *Planorbis trivolvis*. In Siberia this position is taken by *P. corneus*. *Lymnaea palustris*

is not as common in Siberia as in Canada, and possibly it is displaced to some extent in the pond fauna of the former country by *Lymnaea pereger*, a species which does not occur in North America.

Examples

1. A pond at Mile 95, G.W.W.D. Ry., Man. *Lymnaea lanceata.*
2. The smaller Trefoil Lake, near Jasper, Alta. *Planorbis crista.*
3. Lake Dorothy, Miette Valley, Jasper. *Physa gyrina.*
4. Rainy Lake, near Wade, Ont. *Sphaerium sulcatum.*
5. A pond on Duck Mountain, 20 miles east of Kamsack, Sask. *Lymnaea palustris, Planorbis trivolvis.*
6. A pond formed by beavers on Tekarra Creek, Jasper. *Planorbis arcticus, Physa gyrina.*
7. Skunk Lake, near Minaki, Ont. *Sphaerium truncatum, Pisidium tenuissimum.*
8. Sword Lake, near Minaki. *Planorbis campanulatus wisconsinensis, Physa integra.*
9. Virl Lake, Miette Valley, Jasper. *Planorbis crista, Physa gyrina.*
10. Low-lying ground near Round Lake, Ninette, Man. *Lymnaea humilis modicella, L. obrussa exigua.*
11. Alice Lake, near Minaki. *Planorbis campanulatus wisconsinensis, P. arcticus, Musculium securis.*
12. A pond formed by beavers on a small stream crossing Buffalo Prairie, Athabasca Valley, near Jasper. *Lymnaea stagnalis wasatchensis, L. traskii, Planorbis arcticus, Physa gyrina.*
13. A pond near the shore of Hudson Bay, east of Fort Churchill, Man. *Lymnaea palustris, Planorbis arcticus, Physa gyrina, Aplexa hypnorum.*
14. A pond on Moose Mountain, southern Sask. *Lymnaea stagnalis jugularis, L. palustris, Planorbis trivolvis, P. exacuous, Physa gyrina.*
15. A small lake near Cottonwood Creek, Jasper. *Lymnaea stagnalis wasatchensis, L. emarginata canadensis, L. dalli, Planorbis trivolvis, P. hirsutus, P. arcticus, Pisidium roperi, P. splendidulum.*
16. "Lake No. 1", Miette Valley, Jasper. *Planorbis exacuous, P. hirsutus, P. arcticus, Physa gyrina, Ancylus coloradensis, Valvata lewisi, Pisidium* sp.
17. Lake Mildred, near Jasper. *Lymnaea stagnalis wasatchensis, L. palustris, L. obrussa decampi, Planorbis arcticus, Physa gyrina, Valvata lewisi.*
18. Douglas Lake, near Onah, Man. *Lymnaea stagnalis jugularis, L. palustris, Planorbis campanulatus davisi, P. trivolvis, P. exacuous, Physa gyrina.*
19. The larger Trefoil Lake, Jasper. *Lymnaea stagnalis wasatchensis, Planorbis trivolvis, P. exacuous, P. arcticus, Physa gyrina, Pisidium tenuissimum.*
20. Pelican Lake, Ninette, Man. (i) On *Potamogeton* near the centre of the lake, *Physa gyrina* (abundant), *Lymnaea palustris* (less common); (ii) in *Typha* and *Scirpus* marsh around the shore of the lake, *Lymnaea*

stagnalis jugularis, L. palustris, Planorbis exacuous, P. arcticus, Planorbula armigera, Physa gyrina; (iii) in a moist meadow on slightly higher ground near the marsh, *Lymnaea caperata, L. parva* var., *Aplexa hypnorum.*

Large Lakes Having Outlet Streams

Large lakes are numerous in sub-arctic Canada, and their outstanding characteristic is that they are of moderate depth (commonly up to 30 m.), and that their shores are subject to severe wave action. In places where the shores are protected either as a result of their configuration or the presence of islands, the molluscan fauna is similar to that found in smaller bodies of water. The most typical species on exposed shores are *Lymnaea stagnalis sanctaemariae, L. emarginata,* and *L. catascopium.* Fresh-water mussels are to be found on the bottom of many lakes, the commonest species being *Lampsilis siliquoidea rosacea* and *Anodonta kennicotti.*

Few comparable habitats are to be found in Siberia, where there is little or no adaptation in the pulmonate fauna to meet lacustrine conditions such as is found in Canada. The fauna of Lake Baikal, while lacustrine, is of such a special type that no parallel can be drawn between it and any Canadian lake. *Lymnaea stagnalis sanctaemariae* of Canada is a variety which occupies a habitat very similar to that of *L. stagnalis lacustris* in Europe, and the shells of the two varieties have a certain resemblance to each other. *Lymnaea stagnalis lillianae* may also have a parallel form in Europe, *e.g.*, the large variety of *L. stagnalis* which inhabits Lohja Lake in southern Finland.

Examples

1. Maligne Lake, 30 miles east of Jasper, Alta. Altitude 5555 ft. *Lymnaea traskii.*
2. Pyramid Lake, near Jasper. Altitude 3867 ft. *Lymnaea stagnalis wasatchensis, Planorbis antrosus sayi, P. exacuous, P. hirsutus, P. arcticus, Physa gyrina, Pisidium* spp.
3. Atikameg Lake, Mile 17, Hudson Bay Railway, Man. *Lymnaea emarginata* var., *L. obrussa decampi, Planorbis exacuous, P. deflectus, P. hirsutus, Valvata tricarinata.*
4. Shoal Lake, eastern Man. (i) Exposed rocky shores of Indian Bay, *Physa ancillaria;* (ii) sandy shore of Indian Bay somewhat exposed to wave action, *Lymnaea stagnalis lillianae;* (iii) protected shore of Indian Bay, *Lymnaea obrussa exigua;* (iv) Falcon Bay in quiet water, on sand bottom and in small marshes, *Lymnaea stagnalis jugularis, Planorbis campanulatus wisconsinensis, P. trivolvis pilsbryi, P. antrosus sayi, P. exacuous, P. hirsutus, P. arcticus, Planorbula crassilabris, Sphaerium crassum, Anodonta kennicotti.*
5. Lake Brereton, Man. (i) On exposed rocky shores subject to severe wave action, *Lymnaea stagnalis sanctaemariae, Planorbis antrosus sayi, P. campanulatus wisconsinensis, Physa gyrina;* (ii) on partly protected rocky shores, *Lymnaea columella casta, Planorbis exacuous;* (iii) on

partly protected sandy shores, chiefly on *Potamogeton*, *Amnicola limosa;* (iv) on *Potamogeton* and other plants in bays protected from wave action, *Lymnaea megasoma*, *Planorbula crassilabris*, *Pisidium adamsi*; (v) in *Typha* marsh at the mouth of the Rennie River, *Lymnaea megasoma*, *L. lanceata*, *Planorbis antrosus sayi*, *P. exacuous*, *P. arcticus*, *P. hirsutus*, *Physa gyrina*, *Ferrissia parallela*, *Musculium securis*.

6. Lake Winnipeg, near Victoria Beach, Man. (i) On shore stones and boulders subject to severe wave action, *Lymnaea emarginata*, *L. catascopium;* (ii) sandy shore, species cast up from deeper water, *Valvata tricarinata*, *Amnicola limosa porata*, *A. walkeri*, *Musculium transversum*, *Anodonta kennicotti*, *Lampsilis siliquoidea rosacea*, *L. ventricosa;* (iii) small shallow sandy bay containing very little vegetation, *Lymnaea palustris*, *Sphaerium tenue;* (iv) large marsh partly cut off from the lake proper, *Lymnaea stagnalis*, *L. palustris*, *L. dalli*, *Planorbis trivolvis*, *P. hirsutus*, *P. arcticus*, *Planorbula crassilabris*, *Physa gyrina*, *Aplexa hypnorum*, *Valvata lewisi*, *Musculium ryckholti*, *M. truncatum*, *Pisidium roperi*. Note: *Campeloma decisum* was not collected in this marsh, but occurs in the Grand Marais, a similar habitat on the shore of Lake Winnipeg about 15 miles south of Victoria Beach.

Lakes Without Direct Outlet Streams

Lakes of this type are the reservoirs of inland drainage basins which have lost their connection with the sea as a result of changes in climate since the last period of glaciation. As there is no outlet stream to carry off the mineral salts leached from the soils of the basin and carried into the lake by its tributary streams, and the channels of underground drainage are insufficient to do this, these bodies of water are becoming increasingly saline. Such lakes are found in considerable numbers on the Prairie and Parkland, but it is only under special circumstances, such as are found subsequent to forest fires, that they occur in the forested region.

Similar lakes are found in northern Asia, and the mollusca which in that region have the greatest tolerance of saline conditions are *Lymnaea palustris saridalensis*, *L. palustris kazakensis*, and *Planorbis planorbis*.

Examples

1. Little Quill Lake, Sask. Total salt content in 1928, 9688 parts per million. Water analysis given by Mozley (25). *Lymnaea palustris*.
2. Lake Lenore, Sask. Total salt content in 1928, 3936 p.p.m. Water analysis given by Mozley (30). *Lymnaea palustris*, *Planorbis arcticus*.

Intermittent Streams

Many of the smaller channels of drainage in this region contain no water during the period of midsummer drought, and this, coupled with the great force of flood waters when the snow melts in spring, has an unfavorable effect upon the molluscan fauna. In some instances however, where the inclination of the bed of the intermittent stream is slight, so that the freshet has not too

great a scouring effect, a few species find suitable conditions. Where this is so, large numbers of individuals may occur.

Examples

1. A small intermittent stream draining a group of poplar groves near Birtle, Man. *Planorbis umbilicatellus.*
2. Paskwegin Brook, a tributary of Little Quill Lake, Sask. *Lymnaea palustris.*
3. Catfish Creek, near Winnipeg, Man. *Lymnaea palustris, Physa gyrina hildrethiana.*
4. A shallow ditch near Mile 69, G.W.W.D. Ry., Man. *Lymnaea palustris, L. obrussa exigua, Sphaerium occidentale.*
5. A small intermittent stream near Lanigan, Sask. *Lymnaea palustris, L. caperata, Aplexa hypnorum.*

PERMANENT STREAMS OF THE NON-MOUNTAINOUS REGION

There is great diversity in the conditions found in the permanent streams of this area, and hence there are corresponding diversities in the molluscan fauna. It is therefore difficult to give a brief description which will apply to them all. An important characteristic of all, however, is that as they flow through fairly level country the force of the current is only moderate. In many instances this permits the growth of aquatic plants on the bottom, and the development of small marshes along the banks. Under these conditions numerous species of molluscs are to be found. The commonest forms on the Prairie and Parkland are *Lymnaea stagnalis jugularis, Planorbis trivolvis,* and *Lampsilis siliquoidea rosacea. Lasmigona complanata katherinae* is abundant in certain streams. In the forested area *Lampsilis superiorensis* is often the predominant species.

1. In pool just below rapids on a stream entering Lake Nipigon, Ont., at about N. Lat. 49° 25′, W. Long. 80° 8′, near Macdiarmid, Ont. *Physa ancillaria.*
2. Eyehill Creek, near Yonker, Sask. *Lymnaea stagnalis jugularis, Planorbis trivolvis, Aplexa hypnorum.*
3. Clair Brook, a tributary of Little Quill Lake, Sask. *Lymnaea palustris, Planorbis trivolvis, P. arcticus, Aplexa hypnorum.*
4. A small brook running into the Grand Marais, Man. Examined at a point 2 miles east of Balsam Bay. *Lymnaea palustris, L. obrussa exigua, Planorbis arcticus, Planorbula crassilabris, Physa gyrina.*
5. Muckle Creek, near Clandeboye, Man. *Lymnaea stagnalis jugularis, L. palustris, Planorbis arcticus, Physa integra, Valvata tricarinata.*
6. La Salle River, near St. Norbert, Man. *Lymnaea stagnalis jugularis, L. obrussa exigua, Planorbis arcticus, Valvata tricarinata, Amnicola* sp.
7. Jackfish Creek, east of Balsam Bay, Man. *Lymnaea stagnalis jugularis, L. palustris, Planorbis arcticus, P. hirsutus.*

8. Whiteshell River, below Cross Lake, Man. *Lymnaea stagnalis jugularis, L. megasoma, L. lanceata, Planorbis exacuous, P. hirsutus, Aplexa hypnorum, Campeloma decisum.*
9. Birdtail Creek, near Birtle, Man. (i) On bottom of stream, *Planorbis antrosus, Ferrissia rivularis, Physa integra, Lasmigona complanata katherinae, Lampsilis siliquoidea rosacea, Anodonta grandis footiana, Strophitus rugosus;* (ii) in small marshy areas along the banks of the stream, *Lymnaea palustris, L. umbilicata, L. parva sterkii.*
10. A backwater of the Winnipeg River, near Minaki, Ont. *Lymnaea stagnalis jugularis, L. emarginata canadensis, Planorbis corpulentus, P. campanulatus wisconsinensis, P. exacuous, P. arcticus, Physa ancillaria, Sphaerium crassum, Lasmigona complanata katherinae, Lampsilis superiorensis, Anodonta kennicotti.*
11. Red River, near Winnipeg, Man. *Lasmigona complanata katherinae, Lampsilis siliquoidea rosacea, L. ventricosa, Ligumia recta latissima, Proptera alata megaptera, Anodonta grandis footiana, Strophitus rugosus, Amblema costata.*

Streams of the Rocky Mountain Region

It has been pointed out in a previous paper (Mozley (28)) that the conditions of existence in the rivers and brooks of the Rocky Mountain region are not favorable for mollusca. The reasons for this are intimately connected with the climate and topography of the region, and especially with the irregularity of flow in most of the streams, their low temperature, poverty as a nutrient medium, and the high inclination of their beds. Fresh-water mollusca have been found in only one stream in this region, *viz.*, Caledonia Creek, near Jasper, Alta. Conditions in this stream are somewhat unusual for this mountainous part of Canada. Caledonia Creek drains a small lake, which acts as a reservoir, settling basin, and site for food production. *Valvata lewisi* and *Pisidium variabile brevius* were found in the upper part of this stream in considerable numbers.

The Geographical Affinities of the Fauna

The molluscan fauna of the northern part of North America has much in common with that of northern Eurasia. European elements, as distinct from Eurasian, are absent. The fauna of sub-arctic Canada is less rich than that of the more southerly parts of North America, but nevertheless has certain positive characteristics of its own.

There are three geographical elements in this fauna, namely:

(i) A group of circumboreal species, *viz.*, *Lymnaea stagnalis, L. palustris, Planorbis crista, P. hirsutus* (= *albus*), *Aplexa hypnorum* and probably one or more of the Sphaeriidae. In addition, there is one North American species, *Planorbis trivolvis*, which has been found as a fossil in far northeastern Siberia (see Mozley (33)).

(ii) A large number of strictly North American species, the great majority of which are characteristic of the Mississippi drainage, or at least are found

abundantly in that region. An exception to this general rule is *Anodonta marginata* which has long been regarded as characteristic of the Atlantic coast drainage, but is now known to occur in certain parts of the Mississippi drainage.

(iii) A group of species and varieties which is characteristic of sub-arctic Canada, being either wholly confined to it, or else found most commonly within its boundaries. This element includes the following species, *Lymnaea palustris castorensis, L. hedleyi, L. preblei, L. randolphi, L. atkaensis, Planorbis corpulentus, P. corpulentus multicostatum, Planorbula campestris, Amnicola winkleyi mozleyi, Anodonta kennicotti, Lampsilis superiorensis,* and *Lasmigona complanata katherinae.*

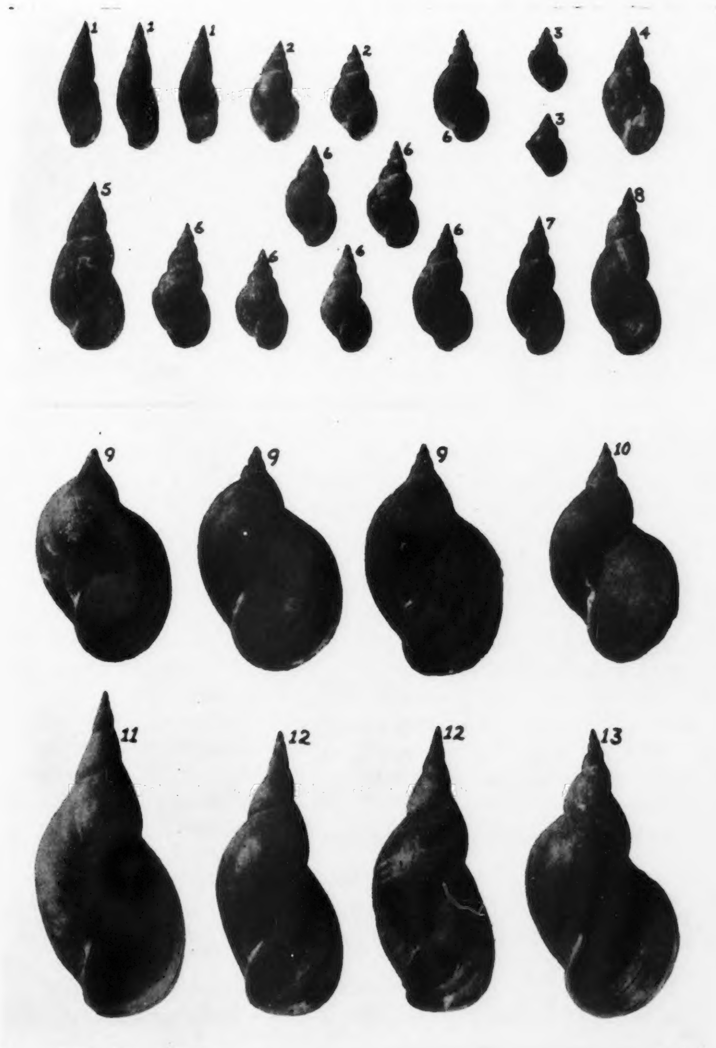
The explanation of the close relationship of the molluscan fauna of sub-arctic Canada with that of the Mississippi drainage lies in the history of the region. By far the greater part of northern North America has been subject to severe glaciation within recent times. The preglacial fauna of this region was either exterminated or driven southward before the ice sheet. After the retreat of the ice the newly exposed territory was repopulated by plants and animals which migrated northwards from the interior of the continent. General geographical factors tended to exclude the possibility of an extensive faunal migration from the Atlantic and Pacific coast regions. This was particularly true of the aquatic organisms, there being direct drainage connections between central Canada and the Mississippi River system, and little or no connection with the Atlantic and Pacific drainages. The aquatic animals which migrated into this region from the south were subsequently trapped in the northern drainage, and thus lost all possibility of interbreeding with the southern fauna. To this separation is probably due, at least in part, the continuance of the faunistic peculiarities of the northern drainage.

The total number of species and varieties of fresh-water mollusca known to inhabit sub-arctic Canada is 111. In northern Asia, apart from Lake Baikal, there are only 50 species and varieties of these animals (Mozley (33)). As both these faunas have been examined by the same investigator there is some reason for believing that the totals are comparable.

In several groups of these fresh-water mollusca there appears to have been a much greater degree of speciation in North America than in northern Asia. The Lymnaeidae of the two areas afford an example. In sub-arctic Canada, there are 26 species and varieties belonging to this family, whereas in Siberia there are only 12. The distinctly greater degree of specialization for life in certain types of habitat (*e.g.*, temporary ponds, see Mozley (33)) in North America as compared with northern Asia may possibly be a related fact. In any event it is reasonably certain that even though the climate and general types of natural regions in the two territories are similar, there is much greater diversity of fresh-water molluscs in the Canadian fauna than in that of Siberia.

The reason may lie partly in the somewhat richer source of supply which was available in Canada, and the greater facility of migration from south to north in North America, than from west to east in Eurasia. Another important factor may have been the greater variety of suitable aquatic habitats

PLATE I



1. *Lymnaea lanceata (Gould); Canyon Lake, Ont.* 2. *Lymnaea johnsoni (Baker); Yoho Park.* 3. *Lymnaea hedleyi Baker; Fraser River, Lucerne, B.C.* 4. *Lymnaea yukonensis Baker; Chena, Alaska.* 5. *Lymnaea palustris (Müller); pond on Duck Mountain, near Madge Lake, Sask.* 6. *Lymnaea traskii (Tryon); 1 mile west of head of Brazeau Lake, Alta.* 7. *Lymnaea palustris; Paskwegin Brook, Sask.* 8. *Same as 5; Birtle, Man.* 9. *Lymnaea stagnalis sanctaemariae Walker; Lake Brereton, Man.* 10. *Same; St. Mary's River, Sault Ste. Marie. (Bryant Walker coll.).* 11. *Lymnaea stagnalis jugularis Say; Long Lac, Ont.* 12. *Same; Mile 237, Hudson Bay Railway.* 13. *Same; Wintering Lake, H.B. Ry.*

which is available in Canada for settlement by molluscs. Only the northern part of Siberia was glaciated during the Pleistocene period, whereas very nearly the whole of sub-arctic Canada was covered by ice. This has resulted in a somewhat more diversified landscape in Canada as far as the aquatic habitats are concerned. In other words, the ponds, lakes and streams of Canada offer a wider range of habitats than do those of Siberia. The general impression which is gained in travelling through northern Asia is that the landscape, particularly in the south, is more mature than that in Canada, and that the climate for some time past may have been less moist. It should be noted, however, that this conclusion may have been influenced to some extent by the fact that the studies in Siberia were carried out during a period of drought. These differences between the Canadian and Siberian landscapes, if true, might be interpreted as having some effect upon the fauna, in that new species and varieties as they arose would have less chance of finding unoccupied habitats which were suited to their special requirements. This can hardly be considered to be the sole explanation of the condition described, but it is probably an important contributing factor.

A somewhat similar conclusion has been reached by Baker (4) regarding the postglacial molluscan fauna of North America, who states that, "Previous to the Glacial Period the country had been reduced to base-level and probably few lakes existed, the physiography being one of rivers with dendritic form of drainage, like the driftless area in Wisconsin today. After the last invasion, the Wisconsin, the country was greatly changed; in place of rivers there were lakes, swamps, and sluggish rivers. The fauna reacted to this change to such an extent that where previously there had been but one or two varieties in a species, as many as ten developed which were peculiar to the newly glaciated country. Many entirely new species were evolved which have not occurred in any glacial deposits yet examined. The change affected some species more than others, but all have been affected to a noteworthy degree."

Some exception might reasonably be taken to the wording of this statement, but there is little doubt regarding the facts upon which the interpretation is based. On the whole, the conclusion, in so far as it relates to the existence of some relationship between physiography and speciation, appears to be a reasonable one.

Acknowledgment

Owing to the fact that the author is abroad, the galley proof of this paper has been corrected by Mr. A. LaRocque of the Geological Survey, Ottawa, Ontario.

References

This list includes only those papers which are referred to in the text. A full bibliography may be found by consulting the papers of Baker and Cahn (9), Dall (13), and Mozley (30).

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